REPORT

OF THE

FIFTY-SECOND MEETING

OF THE

BRITISH ASSOCIATION

FOR THE

ADVANCEMENT OF SCIENCE;

HELD AT

SOUTHAMPTON IN AUGUST 1882.

LONDON:
JOHN MURRAY, ALBEMARLE STREET.
1883.

Office of the Association: 22 Albemarle Street, London, W.

LONDON: PRINTED BY
SPOTTISWOODE AND CO., NEW-STREET SQUARE
AND PARLIAMENT STREET

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OBJECTS AND RULES

OF

THE ASSOCIATION.

OBJECTS.

The Association contemplates no interference with the ground occupied by other institutions. Its objects are:—To give a stronger impulse and a more systematic direction to scientific inquiry,—to promote the intercourse of those who cultivate Science in different parts of the British Empire, with one another and with foreign philosophers,—to obtain a more general attention to the objects of Science, and a removal of any disadvantages of a public kind which impede its progress.

RULES.

Admission of Members and Associates.

All persons who have attended the first Meeting shall be entitled to become Members of the Association, upon subscribing an obligation to conform to its Rules.

The Fellows and Members of Chartered Literary and Philosophical Societies publishing Transactions, in the British Empire, shall be entitled, in like manner, to become Members of the Association.

The Officers and Members of the Councils, or Managing Committees, of Philosophical Institutions shall be entitled, in like manner, to become Members of the Association.

All Members of a Philosophical Institution recommended by its Council or Managing Committee shall be entitled, in like manner, to become Members of the Association.

Persons not belonging to such Institutions shall be elected by the General Committee or Council, to become Life Members of the Association, Annual Subscribers, or Associates for the year, subject to the approval of a General Meeting.

Compositions, Subscriptions, and Privileges.

Life Members shall pay, on admission, the sum of Ten Pounds. They shall receive *gratuitously* the Reports of the Association which may be published after the date of such payment. They are eligible to all the offices of the Association.

Annual Subscribers shall pay, on admission, the sum of Two Pounds, and in each following year the sum of One Pound. They shall receive *gratuitously* the Reports of the Association for the year of their admission and for the years in which they continue to pay *without intermission* their Annual Subscription. By omitting to pay this subscription in any particular year, Members of this class (Annual Subscribers) *lose for that and*

all future years the privilege of receiving the volumes of the Association *gratis:* but they may resume their Membership and other privileges at any subsequent Meeting of the Association, paying on each such occasion the sum of One Pound. They are eligible to all the Offices of the Association.

ASSOCIATES for the year shall pay on admission the sum of One Pound. They shall not receive *gratuitously* the Reports of the Association, nor be eligible to serve on Committees, or to hold any office.

The Association consists of the following classes:—

1. Life Members admitted from 1831 to 1845 inclusive, who have paid on admission Five Pounds as a composition.
2. Life Members who in 1846, or in subsequent years, have paid on admission Ten Pounds as a composition.
3. Annual Members admitted from 1831 to 1839 inclusive, subject to the payment of One Pound annually. [May resume their Membership after intermission of Annual Payment.]
4. Annual Members admitted in any year since 1839, subject to the payment of Two Pounds for the first year, and One Pound in each following year. [May resume their Membership after intermission of Annual Payment.]
5. Associates for the year, subject to the payment of One Pound.
6. Corresponding Members nominated by the Council.

And the Members and Associates will be entitled to receive the annual volume of Reports, *gratis*, or to *purchase* it at reduced (or Members') price, according to the following specification, viz.:—

1. *Gratis.*—Old Life Members who have paid Five Pounds as a composition for Annual Payments, and previous to 1845 a further sum of Two Pounds as a Book Subscription, or, since 1845, a further sum of Five Pounds.

   New Life Members who have paid Ten Pounds as a composition.

   Annual Members *who have not intermitted* their Annual Subscription.
2. *At reduced or Members' Prices*, viz. two-thirds of the Publication Price.—Old Life Members who have paid Five Pounds as a composition for Annual Payments, but no further sum as a Book Subscription.

   Annual Members who have intermitted their Annual Subscription.

   Associates for the year. [Privilege confined to the volume for that year only.]
3. Members may purchase (for the purpose of completing their sets) any of the volumes of the Reports of the Association up to 1874, *of which more than* 15 *copies remain*, at 2*s*. 6*d*. per volume.[1]

Application to be made at the Office of the Association, 22 Albemarle Street, London, W.

Volumes not claimed within two years of the date of publication can only be issued by direction of the Council.

Subscriptions shall be received by the Treasurer or Secretaries.

[1] A few complete sets, 1831 to 1874, are on sale, £10 the set.

Meetings.

The Association shall meet annually, for one week, or longer. The place of each Meeting shall be appointed by the General Committee two years in advance; and the arrangements for it shall be entrusted to the Officers of the Association.

General Committee.

The General Committee shall sit during the week of the Meeting, or longer, to transact the business of the Association. It shall consist of the following persons:—

CLASS A. PERMANENT MEMBERS.

1. Members of the Council, Presidents of the Association, and Presidents of Sections for the present and preceding years, with Authors of Reports in the Transactions of the Association.

2. Members who by the publication of Works or Papers have furthered the advancement of those subjects which are taken into consideration at the Sectional Meetings of the Association. *With a view of submitting new claims under this Rule to the decision of the Council, they must be sent to the Secretary at least one month before the Meeting of the Association. The decision of the Council on the claims of any Member of the Association to be placed on the list of the General Committee to be final.*

CLASS B. TEMPORARY MEMBERS.

1. The President for the time being of any Scientific Society publishing Transactions or, in his absence, a delegate representing him.[1] *Claims under this Rule to be sent to the Secretary before the opening of the Meeting.*

2. Office-bearers for the time being, or delegates, altogether not exceeding three, from Scientific Institutions established in the place of Meeting. *Claims under this Rule to be approved by the Local Secretaries before the opening of the Meeting.*

3. Foreigners and other individuals whose assistance is desired, and who are specially nominated in writing, for the Meeting of the year, by the President and General Secretaries.

4. Vice-Presidents and Secretaries of Sections.

Organizing Sectional Committees.[2]

The Presidents, Vice-Presidents, and Secretaries of the several Sections are nominated by the Council, and have power to act until their names are submitted to the General Committee for election.

From the time of their nomination they constitute Organizing Committees for the purpose of obtaining information upon the Memoirs and Reports likely to be submitted to the Sections,[3] and of preparing Reports thereon, and on the order in which it is desirable that they should be

[1] Revised by the General Committee, Southampton, 1882.
[2] Passed by the General Committee, Edinburgh, 1871.
[3] *Notice to Contributors of Memoirs.*—Authors are reminded that, under an arrangement dating from 1871, the acceptance of Memoirs, and the days on which they are to be read, are now as far as possible determined by Organizing Committees for the several Sections *before the beginning of the Meeting.* It has therefore become necessary, in order to give an opportunity to the Committees of doing justice to the several Communications, that each Author should prepare an Abstract of his Memoir, of a length suitable for insertion in the published Transactions of the Association,

read, to be presented to the Committees of the Sections at their first meeting. The Sectional Presidents of former years are *ex officio* members of the Organizing Sectional Committees.[1]

An Organizing Committee may also hold such preliminary meetings as the President of the Committee thinks expedient, but shall, under any circumstances, meet on the first Wednesday of the Annual Meeting, at 11 A.M., to nominate the first members of the Sectional Committee, if they shall consider it expedient to do so, and to settle the terms of their report to the General Committee, after which their functions as an Organizing Committee shall cease.[2]

Constitution of the Sectional Committees.[3]

On the first day of the Annual Meeting, the President, Vice-Presidents, and Secretaries of each Section having been appointed by the General Committee, these Officers, and those previous Presidents and Vice-Presidents of the Section who may desire to attend, are to meet, at 2 P.M., in their Committee Rooms, and enlarge the Sectional Committees by selecting individuals from among the Members (not Associates) present at the Meeting whose assistance they may particularly desire. The Sectional Committees thus constituted shall have power to add to their number from day to day.

The List thus formed is to be entered daily in the Sectional Minute-Book, and a copy forwarded without delay to the Printer, who is charged with publishing the same before 8 A.M. on the next day in the Journal of the Sectional Proceedings.

Business of the Sectional Committees.

Committee Meetings are to be held on the Wednesday at 2 P.M., on the following Thursday, Friday, Saturday, Monday, and Tuesday, from 10 to 11 A.M., punctually, for the objects stated in the Rules of the Association, and specified below.

The business is to be conducted in the following manner:—

1. The President shall call on the Secretary to read the minutes of the previous Meeting of the Committee.
2. No paper shall be read until it has been formally accepted by the Committee of the Section, and entered on the minutes accordingly.
3. Papers which have been reported on unfavourably by the Organizing Committees shall not be brought before the Sectional Committees.[4]

At the first meeting, one of the Secretaries will read the Minutes of last year's proceedings, as recorded in the Minute-Book, and the Synopsis

and that he should send it, together with the original Memoir, by book-post, on or before........................., addressed thus—'General Secretaries, British Association, 22 Albemarle Street, London, W. For Section ....' If it should be inconvenient to the Author that his paper should be read on any particular days, he is requested to send information thereof to the Secretaries in a separate note. Authors who send in their MSS. three complete weeks before the Meeting, and whose papers are accepted, will be furnished, before the Meeting, with printed copies of their Reports and Abstracts. No Report, Paper, or Abstract can be inserted in the Annual Volume unless it is handed either to the Recorder of the Section or to the Secretary, *before the conclusion of the Meeting.*

[1] Added by the General Committee, Sheffield, 1879.

[2] Revised by the General Committee, Swansea, 1880.

[3] Passed by the General Committee, Edinburgh, 1871.

[4] These rules were adopted by the General Committee, Plymouth, 1877.

of Recommendations adopted at the last Meeting of the Association and printed in the last volume of the Transactions. He will next proceed to read the Report of the Organizing Committee.[1] The list of Communications to be read on Thursday shall be then arranged, and the general distribution of business throughout the week shall be provisionally appointed. At the close of the Committee Meeting the Secretaries shall forward to the Printer a List of the Papers appointed to be read. The Printer is charged with publishing the same before 8 A.M. on Thursday in the Journal.

On the second day of the Annual Meeting, and the following days, the Secretaries are to correct, on a copy of the Journal, the list of papers which have been read on that day, to add to it a list of those appointed to be read on the next day, and to send this copy of the Journal as early in the day as possible to the Printer, who is charged with printing the same before 8 A.M. next morning in the Journal. It is necessary that one of the Secretaries of each Section (generally the Recorder) should call at the Printing Office and revise the proof each evening.

Minutes of the proceedings of every Committee are to be entered daily in the Minute-Book, which should be confirmed at the next meeting of the Committee.

Lists of the Reports and Memoirs read in the Sections are to be entered in the Minute-Book daily, which, with *all Memoirs and Copies or Abstracts of Memoirs furnished by Authors, are to be forwarded, at the close of the Sectional Meetings*, to the Secretary.

The Vice-Presidents and Secretaries of Sections become *ex officio* temporary Members of the General Committee (*vide* p. xxiii), and will receive, on application to the Treasurer in the Reception Room, Tickets entitling them to attend its Meetings.

The Committees will take into consideration any suggestions which may be offered by their Members for the advancement of Science. They are specially requested to review the recommendations adopted at preceding Meetings, as published in the volumes of the Association and the communications made to the Sections at this Meeting, for the purposes of selecting definite points of research to which individual or combined exertion may be usefully directed, and branches of knowledge on the state and progress of which Reports are wanted; to name individuals or Committees for the execution of such Reports or researches; and to state whether, and to what degree, these objects may be usefully advanced by the appropriation of the funds of the Association, by application to Government, Philosophical Institutions, or Local Authorities.

In case of appointment of Committees for special objects of Science, it is expedient that *all Members of the Committee should be named, and one of them appointed to act as Secretary, for insuring attention to business.*

Committees have power to add to their number persons whose assistance they may require.

The recommendations adopted by the Committees of Sections are to be registered in the Forms furnished to their Secretaries, and one Copy of each is to be forwarded, without delay, to the Secretary for presentation to the Committee of Recommendations. *Unless this be done, the Recommendations cannot receive the sanction of the Association.*

N.B.—Recommendations which may originate in any one of the Sections must *first be sanctioned by the Committee of that Section* before they

[1] This and the following sentence were added by the General Committee, 1871.

can be referred to the Committee of Recommendations or confirmed by the General Committee.

The Committees of the Sections shall ascertain whether a Report has been made by every Committee appointed at the previous Meeting to whom a sum of money has been granted, and shall report to the Committee of Recommendations in every case where no such Report has been received.[1]

Notices regarding Grants of Money.

Committees and individuals, to whom grants of money have been entrusted by the Association for the prosecution of particular researches in science, are required to present to each following Meeting of the Association a Report of the progress which has been made; and the Individual or the Member first named of a Committee to whom a money grant has been made must (previously to the next Meeting of the Association) forward to the General Secretaries or Treasurer a statement of the sums which have been expended, and the balance which remains disposable on each grant.

Grants of money sanctioned at any one Meeting of the Association expire *a week before* the opening of the ensuing Meeting; nor is the Treasurer authorized, after that date, to allow any claims on account of such grants, unless they be renewed in the original or a modified form by the General Committee.

No Committee shall raise money in the name or under the auspices of the British Association without special permission from the General Committee to do so; and no money so raised shall be expended except in accordance with the rules of the Association.

In each Committee, the Member first named is the only person entitled to call on the Treasurer, Professor A. W. Williamson, University College, London, W.C., for such portion of the sums granted as may from time to time be required.

In grants of money to Committees, the Association does not contemplate the payment of personal expenses to the members.

In all cases where additional grants of money are made for the continuation of Researches at the cost of the Association, the sum named is deemed to include, as a part of the amount, whatever balance may remain unpaid on the former grant for the same object.

All Instruments, Papers, Drawings, and other property of the Association are to be deposited at the Office of the Association, 22 Albemarle Street, Piccadilly, London, W., when not employed in carrying on scientific inquiries for the Association.

Business of the Sections.

The Meeting Room of each Section is opened for conversation from 10 to 11 daily. *The Section Rooms and approaches thereto can be used for no notices, exhibitions, or other purposes than those of the Association.*

At 11 precisely the Chair will be taken, and the reading of communications, in the order previously made public, commenced. At 3 P.M. the Sections will close.

Sections may, by the desire of the Committees, divide themselves into Departments, as often as the number and nature of the communications delivered in may render such divisions desirable.

[1] Passed by the General Committee at Sheffield, 1879.

A Report presented to the Association, and read to the Section which originally called for it, may be read in another Section, at the request of the Officers of that Section, with the consent of the Author.

Duties of the Doorkeepers.

1.—To remain constantly at the Doors of the Rooms to which they are appointed during the whole time for which they are engaged.

2.—To require of every person desirous of entering the Rooms the exhibition of a Member's, Associate's, or Lady's Ticket, or Reporter's Ticket, signed by the Treasurer, or a Special Ticket signed by the Secretary.

3.—Persons unprovided with any of these Tickets can only be admitted to any particular Room by order of the Secretary in that Room.

No person is exempt from these Rules, except those Officers of the Association whose names are printed in the programme, p. 1.

Duties of the Messengers.

To remain constantly at the Rooms to which they are appointed, during the whole time for which they are engaged, except when employed on messages by one of the Officers directing these Rooms.

Committee of Recommendations.

The General Committee shall appoint at each Meeting a Committee, which shall receive and consider the Recommendations of the Sectional Committees, and report to the General Committee the measures which they would advise to be adopted for the advancement of Science.

All Recommendations of Grants of Money, Requests for Special Researches, and Reports on Scientific Subjects shall be submitted to the Committee of Recommendations, and not taken into consideration by the General Committee unless previously recommended by the Committee of Recommendations.

Local Committees.

Local Committees shall be formed by the Officers of the Association to assist in making arrangements for the Meetings.

Local Committees shall have the power of adding to their numbers those Members of the Association whose assistance they may desire.

Officers.

A President, two or more Vice-Presidents, one or more Secretaries, and a Treasurer shall be annually appointed by the General Committee.

Council.

In the intervals of the Meetings, the affairs of the Association shall be managed by a Council appointed by the General Committee. The Council may also assemble for the despatch of business during the week of the Meeting.

Papers and Communications.

The Author of any paper or communication shall be at liberty to reserve his right of property therein.

Accounts.

The Accounts of the Association shall be audited annually, by Auditors appointed by the General Committee.

Table showing the Places and Times of Meeting of the British Association, with Presidents, Vice-Presidents, and Local Secretaries, from its Commencement.

PRESIDENTS.	VICE-PRESIDENTS.	LOCAL SECRETARIES.
The EARL FITZWILLIAM, D.C.L., F.R.S., F.G.S., &c. YORK, September 27, 1831.	Rev. W. Vernon Harcourt, M.A., F.R.S., F.G.S.	William Gray, jun., Esq., F.G.S. Professor Phillips, M.A., F.R.S., F.G.S.
The REV. W. BUCKLAND, D.D., F.R.S., F.G.S., &c. OXFORD, June 19, 1832.	Sir David Brewster, F.R.S. L. & E., &c. Rev. W. Whewell, F.R.S., Pres. Geol. Soc.	Professor Daubeny, M.D., F.R.S., &c. Rev. Professor Powell, M.A., F.R.S., &c.
The REV. ADAM SEDGWICK, M.A., V.P.R.S., V.P.G.S. CAMBRIDGE, June 25, 1833.	G. B. Airy, Esq., F.R.S., Astronomer Royal, &c. John Dalton, Esq., D.C.L., F.R.S.	Rev. Professor Henslow, M.A., F.L.S., F.G.S. Rev. W. Whewell, F.R.S.
SIR T. MACDOUGALL BRISBANE, K.C.B., D.C.L., F.R.S. L. & E. EDINBURGH, September 8, 1834.	Sir David Brewster, F.R.S., &c. Rev. T. R. Robinson, D.D.	Professor Forbes, F.R.S. L. & E., &c. Sir John Robinson, Sec. R.S.E.
The REV. PROVOST LLOYD, LL.D. DUBLIN, August 10, 1835.	Viscount Oxmantown, F.R.S., F.R.A.S. Rev. W. Whewell, F.R.S., &c.	Sir W. R. Hamilton, Astron. Royal of Ireland, &c Rev. Professor Lloyd, F.R.S.
The MARQUIS OF LANSDOWNE, D.C.L., F.R.S., &c. BRISTOL, August 22, 1836.	The Marquis of Northampton, F.R.S. Rev. W. D. Conybeare, F.R.S., F.G.S. J. C. Prichard, Esq., M.D., F.R.S.	Professor Daubeny, M.D., F.R.S., &c. V. F. Hovenden, Esq.
The EARL OF BURLINGTON, F.R.S., F.G.S., Chancellor of the University of London LIVERPOOL, September 11, 1837.	The Bishop of Norwich, P.L.S., F.G.S. John Dalton, Esq., D.C.L., F.R.S. Sir Philip de Grey Egerton, Bart., F.R.S., F.G.S. Rev. W. Whewell, F.R.S.	Professor Traill, M.D. Wm. Wallace Currie, Esq. Joseph N. Walker, Esq., Pres. Royal Institution, Liverpool.
The DUKE OF NORTHUMBERLAND, F.R.S., F.G.S., &c. NEWCASTLE-ON-TYNE, August 20, 1838.	The Bishop of Durham, F.R.S., F.S.A. The Rev. W. Vernon Harcourt, F.R.S., &c. Prideaux John Selby, Esq., F.R.S.E.	John Adamson, Esq., F.L.S., &c. Wm. Hutton, Esq., F.G.S. Professor Johnston, M.A., F.R.S.
The REV. W. VERNON HARCOURT, M.A., F.R.S., &c. BIRMINGHAM, August 26, 1839.	The Marquis of Northampton. The Earl of Dartmouth. The Rev. T. R. Robinson, D.D. John Corrie, Esq., F.R.S. The Very Rev. Principal Macfarlane	George Barker, Esq., F.R.S. Peyton Blakiston, Esq., M.D. Joseph Hodgson, Esq., F.R.S. Follett Osler, Esq.
The MARQUIS OF BREADALBANE, F.R.S. GLASGOW, September 17, 1840.	Major-General Lord Greenock, F.R.S.E. Sir David Brewster, F.R.S. Sir T. M. Brisbane, Bart., F.R.S. The Earl of Mount-Edgcumbe	Andrew Liddell, Esq. Rev. J. P. Nicol, LL.D. John Strang, Esq.
The REV. PROFESSOR WHEWELL, F.R.S., &c. PLYMOUTH, July 29, 1841.	The Earl of Morley. Lord Eliot, M.P. Sir C. Lemon, Bart. Sir T. D. Acland, Bart.	W. Snow Harris, Esq., F.R.S. Col. Hamilton Smith, F.L.S. Robert Were Fox, Esq. Richard Taylor, jun., Esq.
The LORD FRANCIS EGERTON, F.G.S. MANCHESTER, June 23, 1842.	John Dalton, Esq., D.C.L., F.R.S. Hon. and Rev. W. Herbert, F.L.S., &c. Rev. A. Sedgwick, M.A., F.R.S. W. C. Henry, Esq., M.D., F.R.S. Sir Benjamin Heywood, Bart.	Peter Clare, Esq., F.R.A.S. W. Fleming, Esq., M.D. James Heywood, Esq., F.R.S.
The EARL OF ROSSE, F.R.S. CORK, August 17, 1843.	The Earl of Listowel. Viscount Adare. Sir W. R. Hamilton, Pres. R.I.A. Rev. T. R. Robinson, D.D.	Professor John Stevelly, M.A. Rev. Jos. Carson, F.T.C. Dublin. William Keleher, Esq. Wm. Clear, Esq.

The REV. G. PEACOCK, D.D. (Dean of Ely), F.R.S. YORK, September 26, 1844.	Earl Fitzwilliam, F.R.S. Viscount Morpeth, F.G.S. The Hon. John Stuart Wortley, M.P. Sir David Brewster, K.H., F.R.S. Michael Faraday, Esq., D.C.L., F.R.S. Rev. W. V. Harcourt, F.R.S.	William Hatfeild, Esq., F.G.S. Thomas Meynell, Esq., F.L.S. Rev. W. Scoresby, LL.D., F.R.S. William West, Esq.
SIR JOHN F. W. HERSCHEL, Bart., F.R.S., &c. CAMBRIDGE, June 19, 1845.	The Earl of Hardwicke. The Bishop of Norwich Rev. J. Graham, D.D. Rev. G. Ainslie, D.D. G. B. Airy, Esq., M.A., D.C.L., F.R.S. The Rev. Professor Sedgwick, M.A., F.R.S.	William Hopkins, Esq., M.A., F.R.S. Professor Ansted, M.A., F.R.S.
SIR RODERICK IMPEY MURCHISON, G.C.St.S., F.R.S. SOUTHAMPTON, September 10, 1846.	The Marquis of Winchester. The Earl of Yarborough, D.C.L. Lord Ashburton, D.C.L. Viscount Palmerston, M.P. Right Hon. Charles Shaw Lefevre, M.P. Sir George T. Staunton, Bart., M.P., D.C.L., F.R.S. The Lord Bishop of Oxford, F.R.S. Professor Owen, M.D., F.R.S. The Rev. Professor Powell, F.R.S.	Henry Clark, Esq., M.D. T. H. C. Moody, Esq.
SIR ROBERT HARRY INGLIS, Bart., D.C.L., F.R.S., M.P. for the University of Oxford OXFORD, June 23, 1847.	The Earl of Rosse, F.R.S. The Lord Bishop of Oxford, F.R.S. The Vice-Chancellor of the University Thomas G. Bucknall Estcourt, Esq., D.C.L., M.P. for the University of Oxford. Very Rev. the Dean of Westminster, D.D., F.R.S. Professor Daubeny, M.D., F.R.S. The Rev. Prof. Powell, M.A., F.R.S.	Rev. Robert Walker, M.A., F.R.S. H. Wentworth Acland, Esq., B.M.
The MARQUIS OF NORTHAMPTON, President of the Royal Society, &c. SWANSEA, August 9, 1848.	The Marquis of Bute, K.T. Viscount Adare, F.R.S. Sir H. T. De la Beche, F.R.S., Pres. G.S. The Very Rev. the Dean of Llandaff, F.R.S. Lewis W. Dillwyn, Esq., F.R.S. W. R. Grove, Esq., F.R.S. J. H. Vivian, Esq., M.P., F.R.S. The Lord Bishop of St. David's	Matthew Moggridge, Esq. D. Nicol, Esq., M.D.
The REV. T. R. ROBINSON, D.D., M.R.I.A., F.R.A.S. BIRMINGHAM, September 12, 1849.	The Earl of Harrowby. The Lord Wrottesley, F.R.S. The Right Hon. Sir Robert Peel, Bart., M.P., D.C.L., F.R.S. Charles Darwin, Esq., M.A., F.R.S., Sec. G.S. Professor Faraday, D.C.L., F.R.S. Sir David Brewster, K.H., LL.D., F.R.S. Rev. Prof. Willis, M.A., F.R.S.	Captain Tindal, R.N. William Wills, Esq. Bell Fletcher, Esq., M.D. James Chance, Esq.
SIR DAVID BREWSTER, K.H., LL.D., F.R.S. L. & E., Principal of the United College of St. Salvator and St. Leonard, St. Andrews EDINBURGH, July 21, 1850.	The Right Hon. the Lord Provost of Edinburgh The Earl of Cathcart, K.C.B., F.R.S.E. The Earl of Rosebery, K.T., D.C.L., F.R.S. The Right Hon. David Boyle (Lord Justice-General), F.R.S.E. General Sir Thomas M. Brisbane, Bart., D.C.L., F.R.S., Pres. R.S.E. The Very Rev. John Lee, D.D., V.P.R.S.E., Principal of the University of Edinburgh. Professor W. P. Alison, M.D., V.P.R.S.E. Professor J. D. Forbes, F.R.S., Sec. R.S.E.	Rev. Professor Kelland, M.A., F.R.S. L. & E. Professor Balfour, M.D., F.R.S.E., F.L.S. James Tod, Esq., F.R.S.E.
GEORGE BIDDELL AIRY, Esq., D.C.L., F.R.S., Astronomer Royal IPSWICH, July 2, 1851.	The Lord Rendlesham, M.P. The Lord Bishop of Norwich Rev. Professor Sedgwick, M.A., F.R.S. Rev. Professor Henslow, M.A., F.L.S. Sir John P. Boileau, Bart., F.R.S. Sir William F. F. Middleton, Bart. J. C. Cobbold, Esq., M.P. T. B. Western, Esq.	Charles May, Esq., F.R.A.S. Dillwyn Sims, Esq. George Arthur Biddell, Esq. George Ransome, Esq., F.L.S.

PRESIDENTS.	VICE-PRESIDENTS.	LOCAL SECRETARIES.
COLONEL EDWARD SABINE, Royal Artillery, Treas. & V.P. of the Royal Society BELFAST, September 1, 1852.	The Earl of Enniskillen, D.C.L., F.R.S. The Earl of Rosse, Pres. R.S., M.R.I.A. Sir Henry T. De la Beche, F.R.S. Rev. Edward Hincks, D.D., M.R.I.A. Rev. P. S. Henry, D.D., Pres. Queen's College, Belfast Rev. T. R. Robinson, D.D., Pres. R.I.A., F.R.A.S. Professor G. G. Stokes, F.R.S. Professor Stevelly, LL.D.	W. J. C. Allen, Esq. William M'Gee, Esq., M.D. Professor W. P. Wilson.
WILLIAM HOPKINS, Esq., M.A., V.P.R.S., F.G.S., Pres. Camb. Phil. Society HULL, September 7, 1853.	The Earl of Carlisle, F.R.S. Lord Londesborough, F.R.S. Professor Faraday, D.C.L., F.R.S. Rev. Prof. Sedgwick, M.A., F.R.S. Charles Frost, Esq., F.S.A., Pres. of the Hull Lit. and Phil. Society William Spence, Esq., F.R.S. Lieut.-Col. Sykes, F.R.S. Professor Wheatstone, F.R.S.	Henry Cooper, Esq., M.D., V.P. Hull Lit. & Phil. Society. Bethel Jacobs, Esq., Pres. Hull Mechanics' Inst.
The EARL OF HARROWBY, F.R.S. LIVERPOOL, September 20, 1854.	The Lord Wrottesley, M.A., F.R.S., F.R.A.S. Sir Philip de Malpas Grey Egerton, Bart., M.P., F.R.S., F.G.S. Professor Owen, M.D., LL.D., F.R.S., F.L.S., F.G.S. Rev. Professor Whewell, D.D., F.R.S., Hon. M.R.I.A., F.G.S., Master of Trinity College, Cambridge William Lassell, Esq., F.R.S. L. & E., F.R.A.S. Joseph Brooks Yates, Esq., F.S.A., F.R.G.S	Joseph Dickinson, Esq., M.D., F.R.S. Thomas Inman, Esq., M.D.
The DUKE OF ARGYLL, F.R.S., F.G.S. GLASGOW, September 12, 1855.	The Very Rev. Principal Macfarlane, D.D. Sir William Jardine, Bart., F.R.S.E. Sir Charles Lyell, M.A., LL.D., F.R.S. James Smith, Esq., F.R.S. L. & E. Walter Crum, Esq., F.R.S. Thomas Graham, Esq., M.A., F.R.S., Master of the Royal Mint Professor William Thomson, M.A., F.R.S.	John Strang, Esq., LL.D. Professor Thomas Anderson, M.D. William Gourlie, Esq.
CHARLES G. B. DAUBENY, Esq., M.D., LL.D., F.R.S., Professor of Botany in the University of Oxford CHELTENHAM, August 6, 1856.	The Earl of Ducie, F.R.S., F.G.S. The Lord Bishop of Gloucester and Bristol Sir Roderick I. Murchison, G.C.St.S., D.C.L., F.R.S. Thomas Barwick Lloyd Baker, Esq. The Rev. Francis Close, M.A.	Capt. Robinson, R.A. Richard Beamish, Esq., F.R.S. John West Hugell, Esq.
The REV. HUMPHREY LLOYD, D.D., D.C.L., F.R.S. L. & E., V.P.R.I.A. DUBLIN, August 26, 1857.	The Right Hon. the Lord Mayor of Dublin The Provost of Trinity College, Dublin The Marquis of Kildare. Lord Talbot de Malahide. The Lord Chancellor of Ireland The Lord Chief Baron, Dublin Sir William R. Hamilton, LL.D., F.R.A.S., Astronomer Royal of Ireland Lieut.-Colonel Larcom, R.E., LL.D., F.R.S. Richard Griffith, Esq., LL.D., M.R.I.A., F.R.S.E., F.G.S.	Lundy E. Foote, Esq. Rev. Professor Jellett, F.T.C.D. W. Neilson Hancock, Esq., LL.D.
RICHARD OWEN, Esq., M.D., D.C.L., V.P.R.S., F.L.S., F.G.S., Superintendent of the Natural History Departments of the British Museum. LEEDS, September 22, 1858.	The Lord Monteagle, F.R.S. The Lord Viscount Goderich, M.P., F.R.G.S. The Right Hon. M. T. Baines, M.A., M.P. Sir Philip de Malpas Grey Egerton, Bart., M.P., F.R.S., F.G.S. The Rev. W. Whewell, D.D., F.R.S., Hon. M.R.I.A., F.G.S., F.R.A.S., Master of Trinity College, Cambridge James Garth Marshall, Esq., M.A., F.G.S. R. Monckton Milnes, Esq., D.C.L., M.P., F.R.G.S.	Rev. Thomas Hincks, B.A. W. Sykes Ward, Esq., F.C.S. Thomas Wilson, Esq., M.A.

HIS ROYAL HIGHNESS THE PRINCE CONSORT ABERDEEN, September 14, 1859.	The Duke of Richmond, K.G., F.R.S. The Earl of Aberdeen, LL.D., K.G., K.T., F.R.S. The Lord Provost of the City of Aberdeen Sir John F. W. Herschel, Bart., M.A., D.C.L., F.R.S. Sir David Brewster, K.H., D.C.L., F.R.S. Sir Roderick I. Murchison, G.C.St.S., D.C.L., F.R.S. The Rev. W. V. Harcourt, M.A., F.R.S. The Rev. T. R. Robinson, D.D., F.R.S. A. Thomson, Esq., LL.D., F.R.S., Convener of the County of Aberdeen	Professor J. Nicol, F.R.S.E., F.G.S. Professor Fuller, M.A. John F. White, Esq.
The LORD WROTTESLEY, M.A., V.P.R.S., F.R.A.S. OXFORD, June 27, 1860.	The Earl of Derby, K.G., P.C., D.C.L., Chancellor of the Univ. of Oxford The Rev. F. Jeune, D.C.L., Vice-Chancellor of the University of Oxford The Duke of Marlborough, D.C.L., F.G.S., Lord Lieutenant of Oxfordshire The Earl of Rosse, K.P., M.A., F.R.S., F.R.A.S. The Lord Bishop of Oxford, D.D., F.R.S. The Very Rev. H. G. Liddell, D.D., Dean of Christ Church, Oxford Professor Daubeny, M.D., LL.D., F.R.S., F.L.S., F.G.S. Professor Acland, M.D., F.R.S. Professor Donkin, M.A., F.R.S., F.R.A.S.	George Rolleston, Esq., M.D., F.L.S. H. J. S. Smith, Esq., M.A., F.C.S. George Griffith, Esq., M.A., F.C.S.
WILLIAM FAIRBAIRN, Esq., LL.D., C.E., F.R.S. MANCHESTER, September 4, 1861.	The Earl of Ellesmere, F.R.G.S. The Lord Stanley, M.P., D.C.L., F.R.G.S. The Lord Bishop of Manchester, D.D., F.R.S., F.G.S. Sir Philip de Malpas Grey Egerton, Bart., M.P., F.R.S., F.G.S. Sir Benjamin Heywood, Bart., F.R.S. Thomas Bazley, Esq., M.P. James Aspinall Turner, Esq., M.P. James Prescott Joule, Esq., LL.D., F.R.S., Pres. Lit. & Phil. Soc. Manchester Professor E. Hodgkinson, F.R.S., M.R.I.A., M.I.C.E. Joseph Whitworth, Esq., F.R.S., M.I.C.E.	R. D. Darbishire, Esq., B.A., F.G.S. Alfred Neild, Esq. Arthur Ransome, Esq., M.A. Professor H. E. Roscoe, B.A.
The REV. R. WILLIS, M.A., F.R.S., Jacksonian Professor of Natural and Experimental Philosophy in the University of Cambridge CAMBRIDGE, October 1, 1862.	The Rev. the Vice-Chancellor of the University of Cambridge The Very Rev. Harvey Goodwin, D.D., Dean of Ely The Rev. W. Whewell, D.D., F.R.S., Master of Trinity College, Cambridge The Rev. Professor Sedgwick, M.A., D.C.L., F.R.S. The Rev. J. Challis, M.A., F.R.S. G. B. Airy, Esq., M.A., D.C.L., F.R.S., Astronomer Royal Professor G. G. Stokes, M.A., D.C.L., Sec. R.S. Professor J. C. Adams, M.A., D.C.L., F.R.S., Pres. C.P.S.	Professor C. C. Babington, M.A., F.R.S., F.L.S. Professor G. D. Liveing, M.A. The Rev. N. M. Ferrers, M.A.
SIR W. ARMSTRONG, C.B., LL.D., F.R.S. NEWCASTLE-ON-TYNE, August 26, 1863.	Sir Walter C. Trevelyan, Bart., M.A. Sir Charles Lyell, LL.D., D.C.L., F.R.S., F.G.S. Hugh Taylor, Esq., Chairman of the Coal Trade Isaac Lowthian Bell, Esq., Mayor of Newcastle Nicholas Wood, Esq., President of the Northern Institute of Mining Engineers Rev. Temple Chevallier, B.D., F.R.A.S. William Fairbairn, Esq., LL.D., F.R.S.	A. Noble, Esq. Augustus H. Hunt, Esq. R. C. Clapham, Esq.

PRESIDENTS.	VICE-PRESIDENTS.	LOCAL SECRETARIES.
SIR CHARLES LYELL, Bart., M.A., D.C.L., F.R.S. BATH, September 14, 1864.	The Right Hon. the Earl of Cork and Orrery, Lord-Lieutenant of Somersetshire The Most Noble the Marquis of Bath The Right Hon. Earl Nelson The Right Hon. Lord Portman The Very Rev. the Dean of Hereford The Venerable the Archdeacon of Bath W. Tite, Esq., M.P., F.R.S., F.G.S., F.S.A. A. E. Way, Esq., M.P. Francis H. Dickinson, Esq. W. Sanders, Esq., F.R.S., F.G.S.	C. Moore, Esq., F.G.S. C. E. Davis, Esq. The Rev. H. H. Winwood, M.A.
JOHN PHILLIPS, Esq., M.A., LL.D., F.R.S., F.G.S., Professor of Geology in the University of Oxford. BIRMINGHAM, September 6, 1865.	The Right Hon. the Earl of Lichfield, Lord-Lieutenant of Staffordshire The Right Hon. the Earl of Dudley The Right Hon. Lord Leigh, Lord-Lieutenant of Warwickshire The Right Hon. Lord Lyttelton, Lord-Lieutenant of Worcestershire The Right Hon. Lord Wrottesley, M.A., D.C.L., F.R.S., F.R.A.S. The Right Rev. the Lord Bishop of Worcester The Right Hon. C. B. Adderley, M.P. William Scholefield, Esq., M.P. F. Osler, Esq., F.R.S. J. T. Chance, Esq. The Rev. Charles Evans, M.A.	William Mathews, jun., Esq., M.A., F.G.S. John Henry Chamberlain, Esq. The Rev. G. D. Boyle, M.A.
WILLIAM R. GROVE, Esq., Q.C., M.A., F.R.S. NOTTINGHAM, August 22, 1866.	His Grace the Duke of Devonshire, Lord-Lieutenant of Derbyshire His Grace the Duke of Rutland, Lord-Lieutenant of Leicestershire The Right Hon. Lord Belper, Lord-Lieutenant of Nottinghamshire The Right Hon. J. E. Denison, M.P. J. C. Webb, Esq., High-Sheriff of Nottinghamshire Thomas Graham, Esq., F.R.S., Master of the Mint Joseph Hooker, Esq., M.D., F.R.S., F.L.S. John Russell Hinds, Esq., F.R.S., F.R.A.S. T. Close, Esq.	Dr. Robertson. Edward J. Lowe, Esq., F.R.A.S., F.L.S. The Rev. J. F. M'Callan, M.A.
HIS GRACE THE DUKE OF BUCCLEUCH, K.G., D.C.L., F.R.S. DUNDEE, September 4, 1867.	The Right Hon. the Earl of Airlie, K.T. The Right Hon. the Lord Kinnaird, K.T. Sir John Ogilvy, Bart., M.P. Sir Roderick I. Murchison, Bart., K.C.B., LL.D., F.R.S., F.G.S., &c. Sir David Baxter, Bart. Sir David Brewster, D.C.L., F.R.S., Principal of the University of Edinburgh James D. Forbes, Esq., LL.D., F.R.S., Principal of the United College of St. Salvator and St. Leonard, University of St. Andrews	J. Henderson, jun., Esq. John Austin Lake Gloag, Esq. Patrick Anderson, Esq.
JOSEPH DALTON HOOKER, Esq., M.D., D.C.L., F.R.S., F.L.S. NORWICH, August 19, 1868.	The Right Hon. the Earl of Leicester, Lord-Lieutenant of Norfolk Sir John Peter Boileau, Bart., F.R.S. The Rev. Adam Sedgwick, M.A., LL.D., F.R.S., F.G.S., &c., Woodwardian Professor of Geology in the University of Cambridge Sir John Lubbock, Bart., F.R.S., F.L.S., F.G.S. John Couch Adams, Esq., M.A., D.C.L., F.R.S., F.R.A.S., Lowndean Professor of Astronomy and Geometry in the University of Cambridge Thomas Brightwell, Esq.	Dr. Donald Dalrymple. Rev. Joseph Crompton, M.A. Rev. Canon Hinds Howell.

PROFESSOR GEORGE G. STOKES, D.C.L., F.R.S. EXETER, August 18, 1869.	The Right Hon. the Earl of Devon The Right Hon. Sir Stafford H. Northcote, Bart., C.B., M.P., &c. Sir John Bowring, LL.D., F.R.S. William B. Carpenter, Esq., M.D., F.R.S., F.L.S. Robert Were Fox, Esq., F.R.S. W. H. Fox Talbot, Esq., M.A., LL.D., F.R.S., F.L.S.	Henry S. Ellis, Esq., F.R.A.S. John C. Bowring, Esq. The Rev. R. Kirwan.
PROFESSOR T. H. HUXLEY, LL.D., F.R.S. F.G.S. LIVERPOOL, September 14, 1870.	The Right Hon. the Earl of Derby, LL.D., F.R.S. Sir Philip de Malpas Grey Egerton, Bart., M.P. The Right Hon. W. E. Gladstone, D.C.L., M.P. S. R. Graves, Esq., M.P. Sir Joseph Whitworth, Bart., LL.D., D.C.L., F.R.S. James P. Joule, Esq., LL.D., D.C.L., F.R.S. Joseph Mayer, Esq., F.S.A., F.R.G.S.	Rev. W. Banister. Reginald Harrison, Esq. Rev. Henry H. Higgins, M.A. Rev. Dr. A. Hume, F.S.A.
PROFESSOR SIR WILLIAM THOMSON, M.A., LL.D., F.R.S. L. & E. EDINBURGH, August 2, 1871.	His Grace the Duke of Buccleuch, K.G., D.C.L., F.R.S. The Right Hon. the Lord Provost of Edinburgh The Right Hon. John Inglis, LL.D., Lord Justice-General of Scotland Sir Alexander Grant, Bart., M.A., Principal of the University of Edinburgh Sir Roderick I. Murchison, Bart., K.C.B., G.C.St.S., D.C.L., F.R.S. Sir Charles Lyell, Bart., D.C.L., F.R.S., F.G.S. Dr. Lyon Playfair, C.B., M.P., F.R.S. Professor Christison, M.D., D.C.L., Pres. R.S.E. Professor Balfour, F.R.S. L. & E.	Professor A. Crum Brown, M.D., F.R.S.E. J. D. Marwick, Esq., F.R.S.E.
W. B. CARPENTER, Esq., M.D., LL.D., F.R.S., F.L.S. BRIGHTON, August 14, 1872.	The Earl of Chichester, Lord-Lieutenant of the County of Sussex The Duke of Norfolk The Right Hon. the Duke of Richmond, K.G., P.C., D.C.L. The Right Hon. the Duke of Devonshire, K.G., D.C.L., F.G.S. Sir John Lubbock, Bart., M.P., F.R.S., F.L.S., F.G.S. Dr. Sharpey, LL.D., Sec. R.S., F.L.S. Joseph Prestwich, Esq., F.R.S., Pres. G.S.	Charles Carpenter, Esq. The Rev. Dr. Griffith. Henry Willett, Esq.
PROFESSOR ALEXANDER W. WILLIAMSON, Ph.D., F.R.S., F.C.S. BRADFORD, September 17, 1873.	The Right Hon. the Earl of Rosse, F.R.S., F.R.A.S. Lord Houghton, D.C.L., F.R.S. The Right Hon. W. E. Forster, M.P. The Mayor of Bradford. J. P. Gassiot, Esq., D.C.L., F.R.S. Professor Phillips, D.C.L., F.R.S. Sir John Hawkshaw, F.R.S., F.G.S.	The Rev. J. R. Campbell, D.D. Richard Goddard, Esq. Peile Thompson, Esq.
PROFESSOR J. TYNDALL, D.C.L., LL.D., F.R.S. BELFAST, August 19, 1874.	The Right Hon. the Earl of Enniskillen, D.C.L., F.R.S. The Right Hon. the Earl of Rosse, F.R.S. Sir Richard Wallace, Bart., M.P. The Rev. Dr. Henry. The Rev. Dr. Robinson, F.R.S. Dr. Andrews, F.R.S. Professor Stokes, D.C.L., F.R.S.	W. Quartus Ewart, Esq. Professor G. Fuller, C.E. T. Sinclair, Esq.
SIR JOHN HAWKSHAW, C.E., F.R.S., F.G.S. BRISTOL, August 25, 1875.	The Right Hon. the Earl of Ducie, F.R.S., F.G.S. The Right Hon. Sir Stafford H. Northcote, Bart., C.B., M.P., F.R.S. The Mayor of Bristol Major-General Sir Henry C. Rawlinson, K.C.B., LL.D., F.R.S., F.R.G.S. Dr. W. B. Carpenter, LL.D., F.R.S., F.L.S., F.G.S. W. Sanders, Esq., F.R.S., F.G.S.	W. Lant Carpenter, Esq., B.A., B.Sc., F.C.S. John H. Clarke, Esq.

PRESIDENTS.	VICE-PRESIDENTS.	LOCAL SECRETARIES.
PROFESSOR THOMAS ANDREWS, M.D., LL.D., F.R.S., Hon. F.R.S.E. GLASGOW, September 6, 1876.	His Grace the Duke of Argyll, K.T., LL.D., F.R.S. L. & E., F.G.S. The Hon. the Lord Provost of Glasgow Sir William Stirling Maxwell, Bart., M.A., M.P. Sir William Thomson, M.A., LL.D., D.C.L., F.R.S. L. & E. Professor Allen Thomson, M.D., LL.D., F.R.S. L. & E. Professor A. C. Ramsay, LL.D., F.R.S., F.G.S. James Young, Esq., F.R.S., F.C.S.	Dr. W. G. Blackie, F.R.G.S. James Grahame, Esq. J. D. Marwick, Esq.
PROFESSOR ALLEN THOMSON, M.D., LL.D., F.R.S. L. & E. PLYMOUTH, August 15, 1877.	The Right Hon. the Earl of Mount-Edgcumbe The Right Hon. Lord Blachford, K.C.M.G. William Spottiswoode, Esq., M.A., LL.D., F.R.S., F.R.A.S., F.R.G.S. William Froude, Esq., M.A., C.E., F.R.S. Charles Spence Bate, Esq., F.R.S., F.L.S.	William Adams, Esq. William Square, Esq. Hamilton Whiteford, Esq.
WILLIAM SPOTTISWOODE, Esq., M.A., D.C.L., LL.D., F.R.S., F.R.A.S., F.R.G.S. DUBLIN, August 14, 1878.	The Right Hon. the Lord Mayor of Dublin The Provost of Trinity College, Dublin His Grace the Duke of Abercorn, K.G. The Right Hon. the Earl of Enniskillen, D.C.L., F.R.S., F.G.S. The Right Hon. the Earl of Rosse, B.A., D.C.L., F.R.S., F.R.A.S., M.R.I.A. The Right Hon. Lord O'Hagan, M.R.I.A. Professor G. G. Stokes, M.A., D.C L., LL.D., Sec. R.S.	Professor R. S. Ball, M.A., F.R.S. James Goff, Esq. John Norwood, Esq., LL.D. Professor G. Sigerson, M.D.
PROFESSOR G. J. ALLMAN, M.D., LL.D., F.R.S. L. & E., M.R.I.A., Pres. L.S. SHEFFIELD, August 20, 1879.	His Grace the Duke of Devonshire, K.G., M.A., LL.D., F.R.S., F.R.G.S. The Right Hon. the Earl Fitzwilliam, K.G., F.R.G.S. The Right Hon. the Earl of Wharncliffe, F.R.G.S. W. H. Brittain, Esq. (Master Cutler) Professor T. H. Huxley, Ph.D., LL.D., Sec. R.S., F.L.S., F.G.S. Professor W. Odling, M.B., F.R.S., F.C.S.	H. Clifton Sorby, Esq., LL.D., F.R.S., F.G.S. J. F. Moss, Esq.
ANDREW CROMBIE RAMSAY, Esq., LL.D., F.R.S., V.P.G.S., Director-General of the Geological Survey of the United Kingdom, and of the Museum of Practical Geology. SWANSEA, August 25, 1880.	The Right Hon. the Earl of Jersey The Mayor of Swansea The Hon. Sir W. R. Grove, M.A., D.C.L., F.R.S. H. Hussey Vivian, Esq., M.P., F.G S. L. Ll. Dillwyn, Esq., M P., F.L.S., F.G.S. J. Gwyn Jeffreys, Esq., LL.D., F.R.S., F.L S., Treas. G.S., F.R.G.S.	W. Morgan Esq., Ph.D., F.C.S. James Strick, Esq.
SIR JOHN LUBBOCK, Bart., M.P., D.C.L., LL.D., F.R.S., Pres. L.S., F.G.S. YORK, August 31, 1881.	His Grace the Archbishop of York, D.D., F.R.S. The Right Hon. the Lord Mayor of York The Right Hon. Lord Houghton, D.C.L., F.R.S., F.R.G.S. The Venerable Archdeacon Creyke, M.A. The Hon. Sir W. R. Grove, M.A., D.C.L., F.R.S. Professor G. G. Stokes, M.A., D.C.L., LL.D., Sec. R S. Sir John Hawkshaw, C.E., F.R S., F.G.S., F.R.G.S. Allen Thomson, Esq., M.D., LL.D., F.R.S. L. & E. Professor Allman, M.D., LL.D., F.R.S. L. & E., F.L.S.	Rev. Thomas Adams, M.A. Tempest Anderson, Esq., M.D., B.Sc.
C. W. SIEMENS, Esq., D.C.L., LL.D., F.R.S., F.C.S., M.I.C.E. SOUTHAMPTON, August 23, 1882.	The Right Hon. the Lord Mount-Temple Captain Sir F. J. Evans, K.C B., F.R.S., F.R.A.S., F.R.G.S., Hydrographer to the Admiralty F. A. Abel, Esq., C.B., F.R.S., V.P.C.S., Director of the Chemical Establishment of the War Department Professor De Chaumont, M.D., F.R.S. Major-General A. C. Cooke, R.E., C.B., F.R.G.S., Director-General of the Ordnance Survey Wyndham S. Portal, Esq. Professor Prestwich, M.A., F.R.S., F.G.S., F.C.S. Philip Lutley Sclater, Esq., M.A., Ph.D., F.R.S., F.L.S., F.G.S.	C. W. A. Jellicoe, Esq. John E. Le Feuvre, Esq. Morris Miles, Esq.

Presidents and Secretaries of the Sections of the Association.

MATHEMATICAL AND PHYSICAL SCIENCES.

COMMITTEE OF SCIENCES, I.—MATHEMATICS AND GENERAL PHYSICS.

Date and Place	Presidents	Secretaries
1832. Oxford......	Davies Gilbert, D.C.L., F.R.S.	Rev. H. Coddington.
1833. Cambridge	Sir D. Brewster, F.R.S.	Prof. Forbes.
1834. Edinburgh	Rev. W. Whewell, F.R.S.	Prof. Forbes, Prof. Lloyd.

SECTION A.—MATHEMATICS AND PHYSICS.

Date and Place	Presidents	Secretaries
1835. Dublin......	Rev. Dr. Robinson	Prof. Sir W. R. Hamilton, Prof. Wheatstone.
1836. Bristol......	Rev. William Whewell, F.R.S.	Prof. Forbes, W. S. Harris, F. W. Jerrard.
1837. Liverpool...	Sir D. Brewster, F.R.S.	W. S. Harris, Rev. Prof. Powell, Prof. Stevelly.
1838. Newcastle	Sir J. F. W. Herschel, Bart., F.R.S.	Rev. Prof. Chevallier, Major Sabine, Prof. Stevelly.
1839. Birmingham	Rev. Prof. Whewell, F.R.S....	J. D. Chance, W. Snow Harris, Prof. Stevelly.
1840. Glasgow ...	Prof. Forbes, F.R.S............	Rev. Dr. Forbes, Prof. Stevelly, Arch. Smith.
1841. Plymouth	Rev. Prof. Lloyd, F.R.S.......	Prof. Stevelly.
1842. Manchester	Very Rev. G. Peacock, D.D., F.R.S.	Prof. M'Culloch, Prof. Stevelly, Rev. W. Scoresby.
1843. Cork.........	Prof. M'Culloch, M.R.I.A. ...	J. Nott, Prof. Stevelly.
1844. York.........	The Earl of Rosse, F.R.S. ...	Rev. Wm. Hey, Prof. Stevelly.
1845. Cambridge	The Very Rev. the Dean of Ely.	Rev. H. Goodwin, Prof. Stevelly, G. G. Stokes.
1846. Southampton.	Sir John F. W. Herschel, Bart., F.R.S.	John Drew, Dr. Stevelly, G. G. Stokes.
1847. Oxford......	Rev. Prof. Powell, M.A., F.R.S.	Rev. H. Price, Prof. Stevelly, G. G. Stokes.
1848. Swansea ...	Lord Wrottesley, F.R.S.	Dr. Stevelly, G. G. Stokes.
1849. Birmingham	William Hopkins, F.R.S.......	Prof. Stevelly, G. G. Stokes, W. Ridout Wills.
1850. Edinburgh	Prof. J. D. Forbes, F.R.S., Sec. R.S.E.	W. J. Macquorn Rankine, Prof. Smyth, Prof. Stevelly, Prof. G. G. Stokes.
1851. Ipswich ...	Rev. W. Whewell, D.D., F.R.S., &c.	S. Jackson, W. J. Macquorn Rankine, Prof. Stevelly, Prof. G. G. Stokes.
1852. Belfast......	Prof. W. Thomson, M.A., F.R.S. L. & E.	Prof. Dixon, W. J. Macquorn Rankine, Prof. Stevelly, J. Tyndall.
1853. Hull.........	The Very Rev. the Dean of Ely, F.R.S.	B. Blaydes Haworth, J. D. Sollitt, Prof. Stevelly, J. Welsh.
1854. Liverpool...	Prof. G. G. Stokes, M.A., Sec. R.S.	J. Hartnup, H. G. Puckle, Prof. Stevelly, J. Tyndall, J. Welsh.
1855. Glasgow ...	Rev. Prof. Kelland, M.A., F.R.S. L. & E.	Rev. Dr. Forbes, Prof. D. Gray, Prof. Tyndall.
1856. Cheltenham	Rev. R. Walker, M.A., F.R.S.	C. Brooke, Rev. T. A. Southwood, Prof. Stevelly, Rev. J. C. Turnbull.
1857. Dublin......	Rev. T. R. Robinson, D.D., F.R.S., M.R.I.A.	Prof. Curtis, Prof. Hennessy, P. A. Ninnis, W. J. Macquorn Rankine, Prof. Stevelly.
1858. Leeds	Rev. W. Whewell, D.D., V.P.R.S.	Rev. S. Earnshaw, J. P. Hennessy, Prof. Stevelly, H. J. S. Smith, Prof Tyndall.

Date and Place	Presidents	Secretaries
1859. Aberdeen...	The Earl of Rosse, M.A., K.P., F.R.S.	J. P. Hennessy, Prof. Maxwell, H. J. S. Smith, Prof. Stevelly.
1860. Oxford......	Rev. B. Price, M.A., F.R.S....	Rev. G C. Bell, Rev. T. Rennison, Prof. Stevelly.
1861. Manchester	G. B. Airy, M.A., D.C.L., F.R.S.	Prof. R. B. Clifton, Prof. H. J. S. Smith, Prof. Stevelly.
1862. Cambridge	Prof. G. G. Stokes, M.A., F.R.S.	Prof. R. B. Clifton, Prof. H. J. S. Smith, Prof. Stevelly.
1863. Newcastle	Prof. W. J. Macquorn Rankine, C.E., F.R.S.	Rev. N. Ferrers, Prof. Fuller, F. Jenkin, Prof. Stevelly, Rev. C. T. Whitley.
1864. Bath.........	Prof. Cayley, M.A., F.R.S., F.R.A.S.	Prof. Fuller, F. Jenkin, Rev. G. Buckle, Prof. Stevelly.
1865. Birmingham	W. Spottiswoode, M.A., F.R.S., F.R.A.S.	Rev. T. N. Hutchinson, F. Jenkin, G. S. Mathews, Prof. H. J. S. Smith, J. M. Wilson.
1866. Nottingham	Prof. Wheatstone, D.C.L., F.R.S.	Fleeming Jenkin, Prof. H. J. S. Smith, Rev. S. N. Swann.
1867. Dundee ...	Prof. Sir W. Thomson, D.C.L., F.R.S.	Rev. G. Buckle, Prof. G. C. Foster, Prof. Fuller, Prof. Swan.
1868. Norwich ...	Prof. J. Tyndall, LL.D., F.R.S.	Prof. G. C. Foster, Rev. R. Harley, R. B. Hayward.
1869. Exeter......	Prof. J. J. Sylvester, LL.D., F.R.S.	Prof. G. C. Foster, R. B. Hayward, W. K. Clifford.
1870. Liverpool...	J. Clerk Maxwell, M.A., LL.D., F.R.S.	Prof. W. G. Adams, W. K. Clifford, Prof. G. C. Foster, Rev. W. Allen Whitworth.
1871. Edinburgh	Prof. P. G. Tait, F.R.S.E. ...	Prof. W. G. Adams, J. T. Bottomley, Prof. W. K. Clifford, Prof. J. D. Everett, Rev. R. Harley.
1872. Brighton ...	W. De La Rue, D.C.L., F.R.S.	Prof. W. K. Clifford, J. W. L. Glaisher, Prof. A. S. Herschel, G. F. Rodwell.
1873. Bradford ...	Prof. H. J. S. Smith, F.R.S.	Prof. W. K. Clifford, Prof. Forbes, J. W. L. Glaisher, Prof. A. S. Herschel.
1874. Belfast......	Rev. Prof. J. H. Jellett, M.A.. M.R.I.A.	J. W. L. Glaisher, Prof. Herschel, Randal Nixon, J. Perry, G. F. Rodwell.
1875. Bristol......	Prof. Balfour Stewart, M.A., LL.D., F.R.S.	Prof. W. F. Barrett, J. W. L. Glaisher, C. T. Hudson, G. F. Rodwell.
1876. Glasgow ...	Prof. Sir W. Thomson, M.A., D.C.L., F.R.S.	Prof. W. F. Barrett, J. T. Bottomley, Prof. G. Forbes, J. W. L. Glaisher, T. Muir.
1877. Plymouth...	Prof. G. C. Foster, B.A., F.R.S., Pres. Physical Soc.	Prof. W. F. Barrett, J. T. Bottomley, J. W. L. Glaisher, F. G. Landon.
1878. Dublin......	Rev. Prof. Salmon, D.D., D.C.L., F.R.S.	Prof. J. Casey, G. F. Fitzgerald, J. W. L. Glaisher, Dr. O. J. Lodge.
1879. Sheffield ...	George Johnstone Stoney, M.A., F.R.S.	A. H. Allen, J. W. L. Glaisher, Dr. O. J. Lodge, D. McAlister.
1880. Swansea ...	Prof. W. Grylls Adams, M.A., F.R.S.	W. E. Ayrton, J. W. L. Glaisher, Dr. O. J. Lodge, D. McAlister.
1881. York.........	Prof. Sir W. Thomson, M.A., LL.D., D.C.L., F.R.S.	Prof. W. E. Ayrton, Prof. O. J. Lodge, D. McAlister, Rev. W. Routh.
1882. Southampton.	Rt. Hon. Prof. Lord Rayleigh, M.A., F.R.S.	W. M. Hicks, Prof. O. J. Lodge, D. McAlister, Rev. G. Richardson.

CHEMICAL SCIENCE.

COMMITTEE OF SCIENCES, II.—CHEMISTRY, MINERALOGY.

1832. Oxford......	John Dalton, D.C.L., F.R.S.	James F. W. Johnston.
1833. Cambridge	John Dalton, D.C.L., F.R.S.	Prof. Miller.
1834. Edinburgh	Dr. Hope........................	Mr. Johnston, Dr. Christison.

SECTION B.—CHEMISTRY AND MINERALOGY.

Date and Place	Presidents	Secretaries
1835. Dublin......	Dr. T. Thomson, F.R.S.	Dr. Apjohn, Prof. Johnston.
1836. Bristol......	Rev. Prof. Cumming	Dr. Apjohn, Dr. C. Henry, W. Herapath.
1837. Liverpool...	Michael Faraday, F.R.S.......	Prof. Johnston, Prof. Miller, Dr. Reynolds.
1838. Newcastle	Rev. William Whewell, F.R.S.	Prof. Miller, H. L. Pattinson, Thomas Richardson.
1839. Birmingham	Prof. T. Graham, F.R.S.	Dr. Golding Bird, Dr. J. B. Melson.
1840. Glasgow ...	Dr. Thomas Thomson, F.R.S.	Dr. R. D. Thomson, Dr. T. Clark, Dr. L. Playfair.
1841. Plymouth...	Dr. Daubeny, F.R.S.	J. Prideaux, Robert Hunt, W. M. Tweedy.
1842. Manchester	John Dalton, D.C.L., F.R.S.	Dr. L. Playfair, R. Hunt, J. Graham.
1843. Cork.........	Prof. Apjohn, M.R.I.A.........	R. Hunt, Dr. Sweeny.
1844. York.........	Prof. T. Graham, F.R.S.	Dr. L. Playfair, E. Solly, T. H. Barker.
1845. Cambridge	Rev. Prof. Cumming	R. Hunt, J. P. Joule, Prof. Miller, E. Solly.
1846. Southampton	Michael Faraday, D.C.L., F.R.S.	Dr. Miller, R. Hunt, W. Randall.
1847. Oxford......	Rev. W. V. Harcourt, M.A., F.R.S.	B. C. Brodie, R. Hunt, Prof. Solly.
1848. Swansea ...	Richard Phillips, F.R.S.	T. H. Henry, R. Hunt, T. Williams.
1849. Birmingham	John Percy, M.D., F.R.S.......	R. Hunt, G. Shaw.
1850. Edinburgh	Dr. Christison, V.P.R.S.E.	Dr. Anderson, R. Hunt, Dr. Wilson.
1851. Ipswich ...	Prof. Thomas Graham, F.R.S.	T. J. Pearsall, W. S. Ward.
1852. Belfast......	Thomas Andrews, M.D., F.R.S.	Dr. Gladstone, Prof. Hodges, Prof. Ronalds.
1853. Hull	Prof. J. F. W. Johnston, M.A., F.R.S.	H. S. Blundell, Prof. R. Hunt, T. J. Pearsall.
1854. Liverpool	Prof. W. A. Miller, M.D., F.R.S.	Dr. Edwards, Dr. Gladstone, Dr. Price.
1855. Glasgow ...	Dr. Lyon Playfair, C.B., F.R.S.	Prof. Frankland, Dr. H. E. Roscoe.
1856. Cheltenham	Prof. B. C. Brodie, F.R.S. ...	J. Horsley, P. J. Worsley, Prof. Voelcker.
1857. Dublin......	Prof. Apjohn, M.D., F.R.S., M.R.I.A.	Dr. Davy, Dr. Gladstone, Prof. Sullivan.
1858. Leeds	Sir J. F. W. Herschel, Bart., D.C.L.	Dr. Gladstone, W. Odling, R. Reynolds.
1859. Aberdeen...	Dr. Lyon Playfair, C.B., F.R.S.	J. S. Brazier, Dr. Gladstone, G. D. Liveing, Dr. Odling.
1860. Oxford......	Prof. B. C. Brodie, F.R.S......	A. Vernon Harcourt, G. D. Liveing, A. B. Northcote.
1861. Manchester	Prof. W. A. Miller, M.D., F.R.S.	A. Vernon Harcourt, G. D. Liveing.
1862. Cambridge	Prof. W. A. Miller, M.D., F.R.S.	H. W. Elphinstone, W. Odling, Prof. Roscoe.
1863. Newcastle	Dr. Alex. W. Williamson, F.R.S.	Prof. Liveing, H. L. Pattinson, J. C. Stevenson.
1864. Bath.........	W. Odling, M.B., F.R.S., F.C.S.	A. V. Harcourt, Prof. Liveing, R. Biggs.
1865. Birmingham	Prof. W. A. Miller, M.D., V.P.R.S.	A. V. Harcourt, H. Adkins, Prof. Wanklyn, A. Winkler Wills.
1866. Nottingham	H. Bence Jones, M.D., F.R.S.	J. H. Atherton, Prof. Liveing, W. J. Russell, J. White.
1867. Dundee ...	Prof. T. Anderson, M.D., F.R.S.E.	A. Crum Brown, Prof. G. D. Liveing, W. J. Russell.
1868. Norwich ...	Prof. E. Frankland, F.R.S., F.C.S.	Dr. A. Crum Brown, Dr. W. J. Russell, F. Sutton.
1869. Exeter	Dr. H. Debus, F.R.S., F.C.S.	Prof. A. Crum Brown, Dr. W. J. Russell, Dr. Atkinson.
1870. Liverpool...	Prof. H. E. Roscoe, B.A., F.R.S., F.C.S.	Prof. A. Crum Brown, A. E. Fletcher Dr. W. J. Russell.

Date and Place	Presidents	Secretaries
1871. Edinburgh	Prof. T. Andrews, M.D., F.R.S.	J. T. Buchanan, W. N. Hartley, T. E. Thorpe.
1872. Brighton ...	Dr. J. H. Gladstone, F.R.S....	Dr. Mills, W. Chandler Roberts, Dr. W. J. Russell, Dr. T. Wood.
1873. Bradford ...	Prof. W. J. Russell, F.R.S....	Dr. Armstrong, Dr. Mills, W. Chandler Roberts, Dr. Thorpe.
1874. Belfast......	Prof. A. Crum Brown, M.D., F.R.S.E., F.C.S.	Dr. T. Cranstoun Charles, W. Chandler Roberts, Prof. Thorpe.
1875. Bristol	A. G. Vernon Harcourt, M.A., F.R.S., F.C.S.	Dr. H. E. Armstrong, W. Chandler Roberts, W. A. Tilden.
1876. Glasgow ...	W. H. Perkin, F.R.S.	W. Dittmar, W. Chandler Roberts, J. M. Thomson, W. A. Tilden.
1877. Plymouth...	F. A. Abel, F.R.S., F.C.S. ...	Dr. Oxland, W. Chandler Roberts, J. M. Thomson.
1878. Dublin	Prof. Maxwell Simpson, M.D., F.R.S., F.C.S.	W. Chandler Roberts, J. M. Thomson, Dr. C. R. Tichborne, T. Wills.
1879. Sheffield ...	Prof. Dewar, M.A., F.R.S.	H. S. Bell, W. Chandler Roberts, J. M. Thomson.
1880. Swansea ...	Joseph Henry Gilbert, Ph.D., F.R.S.	H. B. Dixon, Dr. W. R. Eaton Hodgkinson, P. Phillips Bedson, J. M. Thomson.
1881. York.........	Prof. A. W. Williamson, Ph.D., F.R.S.	P. Phillips Bedson, H. B. Dixon, T. Gough.
1882. Southampton.	Prof. G. D. Liveing, M.A., F.R.S.	P. Phillips Bedson, H. B. Dixon, J. L. Notter.

GEOLOGICAL (AND, UNTIL 1851, GEOGRAPHICAL) SCIENCE.

COMMITTEE OF SCIENCES, III.—GEOLOGY AND GEOGRAPHY.

1832. Oxford	R. I. Murchison, F.R.S.	John Taylor.
1833. Cambridge.	G. B. Greenough, F.R.S.......	W. Lonsdale, John Phillips.
1834. Edinburgh.	Prof. Jameson	Prof. Phillips, T. Jameson Torrie, Rev. J. Yates.

SECTION C.—GEOLOGY AND GEOGRAPHY.

1835. Dublin	R. J. Griffith	Captain Portlock, T. J. Torrie.
1836. Bristol	Rev. Dr. Buckland, F.R.S.—*Geography*, R. I. Murchison, F.R.S.	William Sanders, S. Stutchbury, T. J. Torrie.
1837. Liverpool...	Rev. Prof. Sedgwick, F.R.S.—*Geography*, G. B. Greenough, F.R.S.	Captain Portlock, R. Hunter.—*Geography*, Captain H. M. Denham, R.N.
1838. Newcastle..	C. Lyell, F.R.S., V.P.G.S.—*Geography*, Lord Prudhope.	W. C. Trevelyan, Capt. Portlock.—*Geography*, Capt. Washington.
1839. Birmingham	Rev. Dr. Buckland, F.R.S.—*Geography*, G. B. Greenough, F.R.S.	George Lloyd, M.D., H. E. Strickland, Charles Darwin.
1840. Glasgow ...	Charles Lyell, F.R.S.—*Geography*, G. B. Greenough, F.R.S.	W. J. Hamilton, D. Milne, Hugh Murray, H. E. Strickland, John Scoular, M.D.
1841. Plymouth...	H. T. De la Beche, F.R.S. ...	W. J. Hamilton, Edward Moore, M.D., R. Hutton.
1842. Manchester	R. I. Murchison, F.R.S.	E. W. Binney, R. Hutton, Dr. R. Lloyd, H. E. Strickland.
1843. Cork.........	Richard E. Griffith, F.R.S., M.R.I.A.	Francis M. Jennings, H. E. Strickland.

Date and Place	Presidents	Secretaries
1844. York.........	Henry Warburton, M.P., Pres. Geol. Soc.	Prof. Ansted, E. H. Bunbury.
1845. Cambridge.	Rev. Prof. Sedgwick, M.A., F.R.S.	Rev. J. C. Cumming, A. C. Ramsay, Rev. W. Thorp.
1846. Southampton.	Leonard Horner, F.R.S.—*Geography*, G. B. Greenough, F.R.S.	Robert A. Austen, Dr. J. H. Norton, Prof. Oldham.—*Geography*, Dr. C. T. Beke.
1847. Oxford......	Very Rev. Dr. Buckland, F.R.S.	Prof. Ansted, Prof. Oldham, A. C. Ramsay, J. Ruskin.
1848. Swansea ...	Sir H. T. De la Beche, C.B., F.R.S.	Starling Benson, Prof. Oldham, Prof. Ramsay.
1849. Birmingham	Sir Charles Lyell, F.R.S., F.G.S.	J. Beete Jukes, Prof. Oldham, Prof. A. C. Ramsay.
1850. Edinburgh[1]	Sir Roderick I. Murchison, F.R.S.	A. Keith Johnston, Hugh Miller, Prof. Nicol.

SECTION C (*continued*).—GEOLOGY.

1851. Ipswich ...	William Hopkins, M.A., F.R.S.	C. J. F. Bunbury, G. W. Ormerod, Searles Wood.
1852. Belfast......	Lieut.-Col. Portlock, R.E., F.R.S.	James Bryce, James MacAdam, Prof. M'Coy, Prof. Nicol.
1853. Hull.........	Prof. Sedgwick, F.R.S.........	Prof. Harkness, William Lawton.
1854. Liverpool..	Prof. Edward Forbes, F.R.S.	John Cunningham, Prof. Harkness, G. W. Ormerod, J. W. Woodall.
1855. Glasgow ...	Sir R. I. Murchison, F.R.S....	James Bryce, Prof. Harkness, Prof. Nicol.
1856. Cheltenham	Prof. A. C. Ramsay, F.R.S....	Rev. P. B. Brodie, Rev. R. Hepworth, Edward Hull, J. Scougall, T. Wright.
1857. Dublin	The Lord Talbot de Malahide	Prof. Harkness, Gilbert Sanders, Robert H. Scott.
1858. Leeds	William Hopkins, M.A., LL.D., F.R.S.	Prof. Nicol, H. C. Sorby, E. W. Shaw.
1859. Aberdeen..	Sir Charles Lyell, LL.D., D.C.L., F.R.S.	Prof. Harkness, Rev. J. Longmuir, H. C. Sorby.
1860. Oxford	Rev. Prof. Sedgwick, LL.D., F.R.S., F.G.S.	Prof. Harkness, Edward Hull, Capt. D. C. L. Woodall.
1861. Manchester	Sir R. I. Murchison, D.C.L., LL.D., F.R.S.	Prof. Harkness, Edward Hull, T. Rupert Jones, G. W. Ormerod.
1862. Cambridge	J. Beete Jukes, M.A., F.R.S.	Lucas Barrett, Prof. T. Rupert Jones, H. C. Sorby.
1863. Newcastle	Prof. Warington W. Smyth, F.R.S., F.G.S.	E. F. Boyd, John Daglish, H. C. Sorby, Thomas Sopwith.
1864. Bath........	Prof. J. Phillips, LL.D., F.R.S., F.G.S.	W. B. Dawkins, J. Johnston, H. C. Sorby, W. Pengelly.
1865. Birmingham	Sir R. I. Murchison, Bart., K.C.B.	Rev. P. B. Brodie, J. Jones, Rev. E. Myers, H. C. Sorby, W. Pengelly.
1866. Nottingham	Prof. A. C. Ramsay, LL.D., F.R.S.	R. Etheridge, W. Pengelly, T. Wilson, G. H. Wright.
1867. Dundee .	Archibald Geikie, F.R.S., F.G.S.	Edward Hull, W. Pengelly, Henry Woodward.

[1] At a meeting of the General Committee held in 1850, it was resolved 'That the subject of Geography be separated from Geology and combined with Ethnology, to constitute a separate Section, under the title of the "Geographical and Ethnological Section," for Presidents and Secretaries of which see page xliv.

Date and Place	Presidents	Secretaries
1868. Norwich ...	R. A. C. Godwin-Austen, F.R.S., F.G.S.	Rev. O. Fisher, Rev. J. Gunn, W. Pengelly, Rev. H. H. Winwood.
1869. Exeter	Prof. R. Harkness, F.R.S., F.G.S.	W. Pengelly, W. Boyd Dawkins, Rev. H. H. Winwood.
1870. Liverpool...	Sir Philip de M.Grey Egerton, Bart., M.P., F.R.S.	W. Pengelly, Rev. H. H. Winwood, W. Boyd Dawkins, G. H. Morton.
1871. Edinburgh	Prof. A. Geikie, F.R.S., F.G.S.	R. Etheridge, J. Geikie, T. McKenny Hughes, L. C. Miall.
1872. Brighton ...	R. A. C. Godwin-Austen, F.R.S.	L. C. Miall, George Scott, William Topley, Henry Woodward.
1873. Bradford ...	Prof. J. Phillips, D.C.L., F.R.S., F.G.S.	L. C. Miall, R. H. Tiddeman, W. Topley.
1874. Belfast......	Prof. Hull, M.A., F.R.S., F.G.S.	F. Drew, L. C. Miall, R. G. Symes, R. H. Tiddeman.
1875. Bristol	Dr. Thomas Wright, F.R.S.E., F.G.S.	L. C. Miall, E. B. Tawney, W. Topley.
1876. Glasgow ...	Prof. John Young, M.D.	J. Armstrong, F. W. Rudler, W. Topley.
1877. Plymouth...	W. Pengelly, F.R.S.	Dr. Le Neve Foster, R. H. Tiddeman, W. Topley.
1878. Dublin......	John Evans, D.C.L., F.R.S., F.S.A., F.G.S.	E. T. Hardman, Prof. J. O'Reilly, R. H. Tiddeman.
1879. Sheffield ...	Prof. P. Martin Duncan, M.B., F.R.S., F.G.S.	W. Topley, G. Blake Walker.
1880. Swansea ...	H. C. Sorby, LL.D., F.R.S., F.G.S.	W. Topley, W. Whitaker.
1881. York.........	A. C. Ramsay, LL.D., F.R.S., F.G.S.	J. E. Clark, W. Keeping, W. Topley, W. Whitaker.
1882. Southampton.	R. Etheridge, F.R.S., F.G.S.	T. W. Shore, W. Topley, E. Westlake, W. Whitaker.

BIOLOGICAL SCIENCES.

COMMITTEE OF SCIENCES, IV.—ZOOLOGY, BOTANY, PHYSIOLOGY, ANATOMY.

1832. Oxford......	Rev. P. B. Duncan, F.G.S. ...	Rev. Prof. J. S. Henslow.
1833. Cambridge[1]	Rev. W. L. P. Garnons, F.L.S.	C. C. Babington, D.Don.
1834. Edinburgh.	Prof. Graham......................	W. Yarrell, Prof. Burnett.

SECTION D.—ZOOLOGY AND BOTANY.

1835. Dublin......	Dr. Allman........................	J. Curtis, Dr. Litton.
1836. Bristol	Rev. Prof. Henslow	J. Curtis, Prof. Don, Dr. Riley, S. Rootsey.
1837. Liverpool...	W. S. MacLeay..................	C. C. Babington, Rev. L. Jenyns, W. Swainson.
1838. Newcastle	Sir W. Jardine, Bart.	J. E. Gray, Prof. Jones, R. Owen, Dr. Richardson.
1839. Birmingham	Prof. Owen, F.R.S.	E. Forbes, W. Ick, R. Patterson.
1840. Glasgow ...	Sir W. J. Hooker, LL.D.......	Prof. W. Couper, E. Forbes, R. Patterson.
1841. Plymouth...	John Richardson, M.D., F.R.S.	J. Couch, Dr. Lankester, R. Patterson.
1842. Manchester	Hon. and Very Rev. W. Herbert, LL.D., F.L.S.	Dr. Lankester, R. Patterson, J. A. Turner.
1843. Cork.........	William Thompson, F.L.S....	G. J. Allman, Dr. Lankester, R. Patterson.

[1] At this Meeting Physiology and Anatomy were made a separate Committee, for Presidents and Secretaries of which see p. xliii.

Date and Place	Presidents	Secretaries
1844. York.........	Very Rev. the Dean of Manchester.	Prof. Allman, H. Goodsir, Dr. King, Dr. Lankester.
1845. Cambridge	Rev. Prof. Henslow, F.L.S....	Dr. Lankester, T. V. Wollaston.
1846. Southampton.	Sir J. Richardson, M.D., F.R.S.	Dr. Lankester, T. V. Wollaston, H. Wooldridge.
1847. Oxford......	H. E. Strickland, M.A., F.R.S.	Dr. Lankester, Dr. Melville, T. V. Wollaston.

SECTION D (*continued*).—ZOOLOGY AND BOTANY, INCLUDING PHYSIOLOGY.

[For the Presidents and Secretaries of the Anatomical and Physiological Subsections and the temporary Section E of Anatomy and Medicine, see p. xliii.]

1848. Swansea ...	L. W. Dillwyn, F.R.S..........	Dr. R. Wilbraham Falconer, A. Henfrey, Dr. Lankester.
1849. Birmingham	William Spence, F.R.S.	Dr. Lankester, Dr. Russell.
1850. Edinburgh	Prof. Goodsir, F.R.S. L. & E.	Prof. J. H. Bennett, M.D., Dr. Lankester, Dr. Douglas Maclagan.
1851. Ipswich ...	Rev. Prof. Henslow, M.A., F.R.S.	Prof. Allman, F. W. Johnston, Dr. E. Lankester.
1852. Belfast......	W. Ogilby	Dr. Dickie, George C. Hyndman, Dr. Edwin Lankester.
1853. Hull.........	C. C. Babington, M.A., F.R.S.	Robert Harrison, Dr. E. Lankester.
1854. Liverpool...	Prof. Balfour, M.D., F.R.S....	Isaac Byerley, Dr. E. Lankester.
1855. Glasgow ...	Rev. Dr. Fleeming, F.R.S.E.	William Keddie, Dr. Lankester.
1856. Cheltenham	Thomas Bell, F.R.S., Pres.L.S.	Dr. J. Abercrombie, Prof. Buckman, Dr. Lankester.
1857. Dublin......	Prof. W. H. Harvey, M.D., F.R.S.	Prof. J. R. Kinahan, Dr. E. Lankester, Robert Patterson, Dr. W. E. Steele.
1858. Leeds	C. C. Babington, M.A., F.R.S.	Henry Denny, Dr. Heaton, Dr. E. Lankester, Dr. E. Perceval Wright.
1859. Aberdeen...	Sir W. Jardine, Bart., F.R.S.E.	Prof. Dickie, M.D., Dr. E. Lankester, Dr. Ogilvy.
1860. Oxford......	Rev. Prof. Henslow, F.L.S....	W. S. Church, Dr. E. Lankester, P. L. Sclater, Dr. E. Perceval Wright.
1861. Manchester	Prof. C. C. Babington, F.R.S.	Dr. T. Alcock, Dr. E. Lankester, Dr. P. L. Sclater, Dr. E. P. Wright.
1862. Cambridge	Prof. Huxley, F.R.S.	Alfred Newton, Dr. E. P. Wright.
1863. Newcastle	Prof. Balfour, M.D., F.R.S....	Dr. E. Charlton, A. Newton, Rev. H. B. Tristram, Dr. E. P. Wright.
1864. Bath.........	Dr. John E. Gray, F.R.S. ...	H. B. Brady, C. E. Broom, H. T. Stainton, Dr. E. P. Wright.
1865. Birmingham	T. Thomson, M.D., F.R.S. ...	Dr. J. Anthony, Rev. C. Clarke, Rev. H. B. Tristram, Dr. E. P. Wright.

SECTION D (*continued*).—BIOLOGY.[1]

1866. Nottingham	Prof. Huxley, LL.D., F.R.S. —*Physiological Dep.*, Prof. Humphry, M.D., F.R.S.—*Anthropological Dep.*, Alf. R. Wallace, F.R.G.S.	Dr. J. Beddard, W. Felkin, Rev. H. B. Tristram, W. Turner, E. B. Tylor, Dr. E. P. Wright.
1867. Dundee ...	Prof. Sharpey, M.D., Sec. R.S. —*Dep. of Zool. and Bot.*, George Busk, M.D., F.R.S.	C. Spence Bate, Dr. S. Cobbold, Dr. M. Foster, H. T. Stainton, Rev. H. B. Tristram, Prof. W. Turner.

[1] At a meeting of the General Committee in 1865, it was resolved:—'That the title of Section D be changed to Biology;' and 'That for the word "Subsection," in the rules for conducting the business of the Sections, the word "Department" be substituted.'

Date and Place	Presidents	Secretaries
1868. Norwich ...	Rev. M. J. Berkeley, F.L.S. —*Dep. of Physiology*, W. H. Flower, F.R.S.	Dr. T. S. Cobbold, G. W. Firth, Dr. M. Foster, Prof. Lawson, H. T. Stainton, Rev. Dr. H. B. Tristram, Dr. E. P. Wright.
1869. Exeter	George Busk, F.R.S., F.L.S. —*Dep. of Bot. and Zool.*, C. Spence Bate, F.R.S.—*Dep. of Ethno.*, E. B. Tylor.	Dr. T. S. Cobbold, Prof. M. Foster, E. Ray Lankester, Prof. Lawson, H. T Stainton, Rev. H. B. Tristram.
1870. Liverpool...	Prof. G. Rolleston, M.A., M.D., F.R.S., F.L.S.—*Dep. of Anat. and Physiol.*, Prof. M. Foster, M.D., F.L.S.—*Dep. of Ethno.*, J. Evans, F.R.S.	Dr. T. S. Cobbold, Sebastian Evans, Prof. Lawson, Thos. J. Moore, H. T. Stainton, Rev. H. B. Tristram, C. Staniland Wake, E. Ray Lankester.
1871. Edinburgh	Prof. Allen Thomson, M.D., F.R.S.—*Dep. of Bot. and Zool.*, Prof. Wyville Thomson, F.R.S.—*Dep. of Anthropol.*, Prof. W. Turner, M.D.	Dr. T. R. Fraser, Dr. Arthur Gamgee, E. Ray Lankester, Prof. Lawson, H. T. Stainton, C. Staniland Wake, Dr. W. Rutherford, Dr. Kelburne King.
1872. Brighton ...	Sir J. Lubbock, Bart., F.R.S.—*Dep. of Anat. and Physiol.*, Dr. Burdon Sanderson, F.R.S.—*Dep. of Anthropol.*, Col. A. Lane Fox, F.G.S.	Prof. Thiselton-Dyer, H. T. Stainton, Prof. Lawson, F. W. Rudler, J. H. Lamprey, Dr. Gamgee, E. Ray Lankester, Dr. Pye-Smith.
1873. Bradford ...	Prof. Allman, F.R.S.—*Dep. of Anat. and Physiol.*, Prof. Rutherford, M.D.—*Dep. of Anthropol.*, Dr. Beddoe, F.R.S.	Prof. Thiselton-Dyer, Prof. Lawson, R. M'Lachlan, Dr. Pye-Smith, E. Ray Lankester, F. W. Rudler, J. H. Lamprey.
1874. Belfast......	Prof. Redfern, M.D.—*Dep. of Zool. and Bot.*, Dr. Hooker, C.B., Pres.R.S.—*Dep. of Anthrop.*, Sir W. R. Wilde, M.D	W. T. Thiselton-Dyer, R. O. Cunningham, Dr. J. J. Charles, Dr. P. H. Pye-Smith, J. J. Murphy, F. W. Rudler.
1875. Bristol	P. L. Sclater, F.R.S.—*Dep. of Anat. and Physiol.*, Prof. Cleland, M.D., F.R.S.—*Dep. of Anthropol.*, Prof. Rolleston, M.D., F.R.S.	E. R. Alston, Dr. McKendrick, Prof. W. R. M'Nab, Dr. Martyn, F. W. Rudler, Dr. P. H. Pye-Smith, Dr. W. Spencer.
1876. Glasgow ...	A. Russel Wallace, F.R.G.S., F.L.S.—*Dep. of Zool. and Bot.*, Prof. A. Newton, M.A., F.R.S.—*Dep. of Anat. and Physiol.*, Dr. J. G. McKendrick, F.R.S.E.	E. R. Alston, Hyde Clarke, Dr. Knox, Prof. W. R. M'Nab, Dr. Muirhead, Prof. Morrison Watson.
1877. Plymouth...	J. Gwyn Jeffreys, LL.D., F.R.S., F.L.S.—*Dep. of Anat. and Physiol.*, Prof. Macalister, M.D.—*Dep. of Anthropol.*, Francis Galton, M.A., F.R.S.	E. R. Alston, F. Brent, Dr. D. J. Cunningham, Dr. C. A. Hingston, Prof. W. R. M'Nab, J. B. Rowe, F. W. Rudler.
1878. Dublin	Prof. W. H. Flower, F.R.S.—*Dep. of Anthropol.*, Prof. Huxley, Sec. R.S.—*Dep. of Anat. and Physiol.*, R. McDonnell, M.D., F.R.S.	Dr. R. J. Harvey, Dr. T. Hayden, Prof. W. R. M'Nab, Prof. J. M. Purser, J. B. Rowe, F. W. Rudler.
1879. Sheffield ...	Prof. St. George Mivart, F.R.S.—*Dep. of Anthropol.*, E. B. Tylor, D.C.L., F.R.S. —*Dep. of Anat. and Physiol.*, Dr. Pye-Smith.	Arthur Jackson, Prof. W. R. M'Nab, J. B. Rowe, F. W. Rudler, Prof. Schäfer.
1880. Swansea ...	A. C. L. Günther, M.D., F.R.S —*Dep. of Anat. and Physiol.*, F. M. Balfour, M.A., F.R.S.—*Dep. of Anthropol.*, F. W. Rudler, F.G.S.	G. W. Bloxam, John Priestley, Howard Saunders, Adam Sedgwick.

Date and Place	Presidents	Secretaries
1881. York.........	Richard Owen, C.B., M.D., F.R.S.—*Dep. of Anthropol.*, Prof. W. H. Flower, LL.D., F.R.S.—*Dep. of Anat. and Physiol.*, Prof. J. S. Burdon Sanderson, M.D., F.R.S.	G. W. Bloxam, W. A. Forbes, Rev. W. C. Hey, Prof. W. R. M'Nab, W. North, John Priestley, Howard Saunders, H. E. Spencer.
1882. Southampton.	Prof. A. Gamgee, M.D., F.R.S. —*Dep. of Zool. and Bot.*, Prof. M. A. Lawson, M.A., F.L.S.—*Dep. of Anthropol.*, Prof. W. Boyd Dawkins, M.A., F.R.S.	G. W. Bloxam, W. Heape, J. B. Nias, Howard Saunders, A. Sedgwick, T. W. Shore, jun.

ANATOMICAL AND PHYSIOLOGICAL SCIENCES.

COMMITTEE OF SCIENCES, V.—ANATOMY AND PHYSIOLOGY.

1833. Cambridge	Dr. Haviland.....................	Dr. Bond, Mr. Paget.
1834. Edinburgh	Dr. Abercrombie	Dr. Roget, Dr. William Thomson.

SECTION E (UNTIL 1847).—ANATOMY AND MEDICINE.

1835. Dublin	Dr. Pritchard.....................	Dr. Harrison, Dr. Hart.
1836. Bristol	Dr. Roget, F.R.S.	Dr. Symonds.
1837. Liverpool...	Prof. W. Clark, M.D.	Dr. J. Carson, jun., James Long, Dr. J. R. W. Vose.
1838. Newcastle	T. E. Headlam, M.D.	T. M. Greenhow, Dr. J. R. W. Vose.
1839. Birmingham	John Yelloly, M.D., F.R.S....	Dr. G. O. Rees, F. Ryland.
1840. Glasgow ...	James Watson, M.D.	Dr. J. Brown, Prof. Couper, Prof. Reid.
1841. Plymouth...	P. M. Roget, M.D., Sec. R.S.	Dr. J. Butter, J. Fuge, Dr. R. S. Sargent.
1842. Manchester	Edward Holme, M.D., F.L.S.	Dr. Chaytor, Dr. R. S. Sargent.
1843. Cork	Sir James Pitcairn, M.D. ...	Dr. John Popham, Dr. R. S. Sargent.
1844 York	J. C. Pritchard, M.D.	I. Erichsen, Dr. R. S. Sargent.

SECTION E.—PHYSIOLOGY.

1845. Cambridge	Prof. J. Haviland, M.D.	Dr. R. S. Sargent, Dr. Webster.
1846. Southampton.	Prof. Owen, M.D., F.R.S. ...	C. P. Keele, Dr. Laycock, Dr. Sargent.
1847. Oxford[1] ...	Prof. Ogle, M.D., F.R.S.	Dr. Thomas K. Chambers, W. P. Ormerod.

PHYSIOLOGICAL SUBSECTIONS OF SECTION D.

1850. Edinburgh	Prof. Bennett, M.D., F.R.S.E.	
1855. Glasgow ...	Prof. Allen Thomson, F.R.S.	Prof. J. H. Corbett, Dr. J. Struthers.
1857. Dublin......	Prof. R. Harrison, M.D.	Dr. R. D. Lyons, Prof. Redfern.
1858. Leeds	Sir Benjamin Brodie, Bart., F.R.S.	C. G. Wheelhouse.
1859. Aberdeen...	Prof. Sharpey, M.D., Sec.R.S.	Prof. Bennett, Prof. Redfern.
1860. Oxford......	Prof. G. Rolleston, M.D., F.L.S.	Dr. R. M'Donnell, Dr. Edward Smith.
1861. Manchester	Dr. John Davy, F.R.S.L. & E.	Dr. W. Roberts, Dr. Edward Smith.
1862. Cambridge	C. E. Paget, M.D................	G. F. Helm, Dr. Edward Smith.

[1] By direction of the General Committee at Oxford, Sections D and E were incorporated under the name of 'Section D—Zoology and Botany, including Physiology' (see p. xl). The Section being then vacant was assigned in 1851 to Geography.

Date and Place	Presidents	Secretaries
1863. Newcastle	Prof. Rolleston, M.D., F.R.S.	Dr. D. Embleton, Dr. W. Turner.
1864. Bath.........	Dr. Edward Smith, LL.D., F.R.S.	J. S. Bartrum, Dr. W. Turner.
1865. Birminghm.[1]	Prof. Acland, M.D., LL.D., F.R.S.	Dr. A. Fleming, Dr. P. Heslop, Oliver Pembleton, Dr. W. Turner.

GEOGRAPHICAL AND ETHNOLOGICAL SCIENCES.

[For Presidents and Secretaries for Geography previous to 1851, see Section C, p. xxxviii.]

ETHNOLOGICAL SUBSECTIONS OF SECTION D.

1846. Southampton	Dr. Pritchard.....................	Dr. King.
1847. Oxford	Prof. H. H. Wilson, M.A. ...	Prof. Buckley.
1848. Swansea ...	....	G. Grant Francis.
1849. Birmingham	....	Dr. R. G. Latham.
1850. Edinburgh	Vice-Admiral Sir A. Malcolm	Daniel Wilson.

SECTION E.—GEOGRAPHY AND ETHNOLOGY.

1851. Ipswich ...	Sir R. I. Murchison, F.R.S., Pres. R.G.S.	R. Cull, Rev. J. W. Donaldson, Dr. Norton Shaw.
1852. Belfast......	Col. Chesney, R.A., D.C.L., F.R.S.	R. Cull, R. MacAdam, Dr. Norton Shaw.
1853. Hull.........	R. G. Latham, M.D., F.R.S.	R. Cull, Rev. H. W. Kemp, Dr. Norton Shaw.
1854. Liverpool...	Sir R. I. Murchison, D.C.L., F.R.S.	Richard Cull, Rev. H. Higgins, Dr. Ihne, Dr. Norton Shaw.
1855. Glasgow ...	Sir J. Richardson, M.D., F.R.S.	Dr. W. G. Blackie, R. Cull, Dr. Norton Shaw.
1856. Cheltenham	Col. Sir H. C. Rawlinson, K.C.B.	R. Cull, F. D. Hartland, W. H. Rumsey, Dr. Norton Shaw.
1857. Dublin......	Rev. Dr. J. Henthorn Todd, Pres. R.I.A.	R. Cull, S. Ferguson, Dr. R. R. Madden, Dr. Norton Shaw.
1858. Leeds	Sir R. I. Murchison, G.C.St.S., F.R.S.	R. Cull, Francis Galton, P. O'Callaghan, Dr. Norton Shaw, Thomas Wright.
1859. Aberdeen...	Rear-Admiral Sir James Clerk Ross, D.C.L., F.R.S.	Richard Cull, Prof. Geddes, Dr. Norton Shaw.
1860. Oxford......	Sir R. I. Murchison, D.C.L., F.R.S.	Capt. Burrows, Dr. J. Hunt, Dr. C. Lemprière, Dr. Norton Shaw.
1861. Manchester	John Crawfurd, F.R.S..........	Dr. J. Hunt, J. Kingsley, Dr. Norton Shaw, W. Spottiswoode.
1862. Cambridge	Francis Galton, F.R.S..........	J. W. Clarke, Rev. J. Glover, Dr. Hunt, Dr. Norton Shaw, T. Wright.
1863. Newcastle	Sir R. I. Murchison, K.C.B., F.R.S.	C. Carter Blake, Hume Greenfield, C. R. Markham, R. S. Watson.
1864. Bath.........	Sir R. I. Murchison, K.C.B., F.R.S.	H. W. Bates, C. R. Markham, Capt. R. M. Murchison, T. Wright.
1865. Birmingham	Major-General Sir H. Rawlinson, M.P., K.C.B., F.R.S.	H. W. Bates, S. Evans, G. Jabet, C. R. Markham, Thomas Wright.
1866. Nottingham	Sir Charles Nicholson, Bart., LL.D.	H. W. Bates, Rev. E. T. Cusins, R. H. Major, Clements R. Markham, D. W. Nash, T. Wright.
1867. Dundee ...	Sir Samuel Baker, F.R.G.S.	H. W. Bates, Cyril Graham, Clements R. Markham, S. J. Mackie, R. Sturrock.
1868. Norwich ...	Capt. G. H. Richards, R.N., F.R.S.	T. Baines, H. W. Bates, Clements R. Markham, T. Wright.

[1] *Vide* note on page xli.

SECTION E (*continued*).—GEOGRAPHY.

Date and Place	Presidents	Secretaries
1869. Exeter......	Sir Bartle Frere, K.C.B., LL.D., F.R.G.S.	H. W. Bates, Clements R. Markham, J. H. Thomas.
1870. Liverpool...	Sir R. I. Murchison, Bt., K.C.B., LL.D., D.C.L., F.R.S., F.G.S.	H.W.Bates, David Buxton, Albert J. Mott, Clements R. Markham.
1871. Edinburgh	Colonel Yule, C.B., F.R.G.S.	Clements R. Markham, A. Buchan, J. H. Thomas, A. Keith Johnston.
1872. Brighton ...	Francis Galton, F.R.S.........	H. W. Bates, A. Keith Johnston, Rev. J. Newton, J. H. Thomas.
1873. Bradford ...	Sir Rutherford Alcock, K.C.B.	H. W. Bates, A. Keith Johnston, Clements R. Markham.
1874. Belfast......	Major Wilson, R.E., F.R.S., F.R.G.S.	E. G. Ravenstein, E. C. Rye, J. H. Thomas.
1875. Bristol......	Lieut. - General Strachey, R.E., C.S.I., F.R.S., F.R.G.S., F.L.S., F.G.S.	H. W. Bates, E. C. Rye, F. F. Tuckett.
1876. Glasgow ...	Capt. Evans, C.B., F.R.S.......	H. W. Bates, E. C. Rye, R. Oliphant Wood.
1877. Plymouth...	Adm. Sir E. Ommanney, C.B., F.R.S., F.R.G.S., F.R.A.S.	H. W. Bates, F. E. Fox, E. C. Rye.
1878. Dublin......	Prof. Sir C. Wyville Thomson, LL.D., F.R.S.L.&E.	John Coles, E. C. Rye.
1879. Sheffield ...	Clements R. Markham, C.B., F.R.S., Sec. R.G.S.	H. W. Bates, C. E. D. Black, E. C. Rye.
1880. Swansea ...	Lieut.-Gen. Sir J. H. Lefroy, C.B., K.C.M.G., R.A., F.R.S., F.R.G.S.	H. W. Bates, E. C. Rye.
1881. York.........	Sir J. D. Hooker, K.C.S.I., C.B., F.R.S.	J. W. Barry, H. W. Bates.
1882. Southampton.	Sir R. Temple, Bart., G.C.S.I., F.R.G.S.	E. G. Ravenstein, E. C. Rye.

STATISTICAL SCIENCE.

COMMITTEE OF SCIENCES, VI.—STATISTICS.

Date and Place	Presidents	Secretaries
1833. Cambridge	Prof. Babbage, F.R.S.	J. E. Drinkwater.
1834. Edinburgh	Sir Charles Lemon, Bart.......	Dr. Cleland, C. Hope Maclean.

SECTION F.—STATISTICS.

Date and Place	Presidents	Secretaries
1835. Dublin	Charles Babbage, F.R.S.	W. Greg, Prof. Longfield.
1836. Bristol......	Sir Chas. Lemon, Bart., F.R.S.	Rev. J. E. Bromby, C. B. Fripp, James Heywood.
1837. Liverpool...	Rt. Hon. Lord Sandon.........	W. R. Greg, W. Langton, Dr. W. C. Tayler.
1838. Newcastle	Colonel Sykes, F.R.S.	W. Cargill, J. Heywood, W. R. Wood.
1839. Birmingham	Henry Hallam, F.R.S.........	F. Clarke, R. W. Rawson, Dr. W. C. Tayler.
1840. Glasgow ...	Rt. Hon. Lord Sandon, M.P., F.R.S.	C. R. Baird, Prof. Ramsay, R. W. Rawson.
1841 Plymouth...	Lieut.-Col. Sykes, F.R.S......	Rev. Dr. Byrth, Rev. R. Luney, R. W. Rawson.
1842. Manchester	G. W. Wood, M.P., F.L.S. ...	Rev. R. Luney, G. W. Ormerod, Dr. W. C. Tayler.
1843. Cork.........	Sir C. Lemon, Bart., M.P. ...	Dr. D. Bullen, Dr. W. Cooke Tayler.
1844. York.........	Lieut. - Col. Sykes, F.R.S., F.L.S.	J. Fletcher, J. Heywood, Dr. Laycock.
1845. Cambridge	Rt. Hon. the Earl Fitzwilliam	J. Fletcher, Dr. W. Cooke Tayler.

Date and Place	Presidents	Secretaries
1846. Southampton.	G. R. Porter, F.R.S.	J. Fletcher, F. G. P. Neison, Dr. W. C. Tayler, Rev. T. L. Shapcott.
1847. Oxford......	Travers Twiss, D.C.L., F.R.S.	Rev. W. H. Cox, J. J. Danson, F. G. P. Neison.
1848. Swansea ...	J. H. Vivian, M.P., F.R.S.	J. Fletcher, Capt. R. Shortrede.
1849. Birmingham	Rt. Hon. Lord Lyttelton......	Dr. Finch, Prof. Hancock, F. G. P. Neison.
1850. Edinburgh	Very Rev. Dr. John Lee, V.P.R.S.E.	Prof. Hancock, J. Fletcher, Dr. J. Stark.
1851. Ipswich ...	Sir John P. Boileau, Bart. ...	J. Fletcher, Prof. Hancock.
1852. Belfast......	His Grace the Archbishop of Dublin.	Prof. Hancock, Prof. Ingram, James MacAdam, jun.
1853. Hull	James Heywood, M.P., F.R.S.	Edward Cheshire, W. Newmarch.
1854. Liverpool...	Thomas Tooke, F.R.S.	E. Cheshire, J. T. Danson, Dr. W. H. Duncan, W. Newmarch.
855. Glasgow ...	R. Monckton Milnes, M.P. ...	J. A. Campbell, E. Cheshire, W. Newmarch, Prof. R. H. Walsh.

SECTION F (*continued*).—ECONOMIC SCIENCE AND STATISTICS.

1856. Cheltenham	Rt. Hon. Lord Stanley, M.P.	Rev. C. H. Bromby, E. Cheshire, Dr. W. N. Hancock, W. Newmarch, W. M. Tartt.
1857. Dublin......	His Grace the Archbishop of Dublin, M.R.I.A.	Prof. Cairns, Dr. H. D. Hutton, W. Newmarch.
1858. Leeds	Edward Baines	T. B. Baines, Prof. Cairns, S. Brown, Capt. Fishbourne, Dr. J. Strang.
1859. Aberdeen...	Col. Sykes, M.P., F.R.S.	Prof. Cairns, Edmund Macrory, A. M. Smith, Dr. John Strang.
1860. Oxford	Nassau W. Senior, M.A.	Edmund Macrory, W. Newmarch, Rev. Prof. J. E. T. Rogers.
1861. Manchester	William Newmarch, F.R.S....	David Chadwick, Prof. R. C. Christie, E. Macrory, Rev. Prof. J. E. T. Rogers.
1862. Cambridge	Edwin Chadwick, C.B.	H. D. Macleod, Edmund Macrory.
1863. Newcastle .	William Tite, M.P., F.R.S. ...	T. Doubleday, Edmund Macrory, Frederick Purdy, James Potts.
1864. Bath	William Farr, M.D., D.C.L., F.R.S.	E. Macrory, E. T. Payne, F. Purdy.
1865. Birmingham	Rt. Hon. Lord Stanley, LL.D., M.P.	G. J. D. Goodman, G. J. Johnston, E. Macrory.
1866. Nottingham	Prof. J. E. T. Rogers............	R. Birkin, jun., Prof. Leone Levi, E. Macrory.
1867. Dundee	M. E. Grant Duff, M.P.	Prof. Leone Levi, E. Macrory, A. J. Warden.
1868. Norwich	Samuel Brown, Pres. Instit. Actuaries.	Rev. W. C. Davie, Prof. Leone Levi.
1869. Exeter	Rt. Hon. Sir Stafford H. Northcote, Bart., C.B., M.P.	Edmund Macrory, Frederick Purdy, Charles T. D. Acland.
1870. Liverpool...	Prof. W. Stanley Jevons, M.A.	Chas. R. Dudley Baxter, E. Macrory, J. Miles Moss.
1871. Edinburgh	Rt. Hon. Lord Neaves	J. G. Fitch, James Meikle.
1872. Brighton ...	Prof. Henry Fawcett, M.P. ...	J. G. Fitch, Barclay Phillips.
1873. Bradford ...	Rt. Hon. W. E. Forster, M.P.	J. G. Fitch, Swire Smith.
1874. Belfast......	Lord O'Hagan	Prof. Donnell, Frank P. Fellows, Hans MacMordie.
1875. Bristol	James Heywood, M.A., F.R.S., Pres.S.S.	F. P. Fellows, T. G. P. Hallett, E. Macrory.
1876. Glasgow ...	Sir George Campbell, K.C.S.I., M.P.	A. M'Neel Caird, T. G. P. Hallett, Dr. W. Neilson Hancock, Dr. W. Jack.

Date and Place	Presidents	Secretaries
1877. Plymouth...	Rt. Hon. the Earl Fortescue	W. F. Collier, P. Hallett, J. T. Pim.
1878. Dublin......	Prof. J. K. Ingram, LL.D., M.R.I.A.	W. J. Hancock, C. Molloy, J. T. Pim.
1879. Sheffield ...	G. Shaw Lefevre, M.P., Pres. S.S.	Prof. Adamson, R. E. Leader, C. Molloy.
1880. Swansea ...	G. W. Hastings, M.P.	N. A. Humphreys, C. Molloy.
1881. York.........	Rt. Hon. M. E. Grant Duff, M.A., F.R.S.	C. Molloy, W. W. Morrell, J. F. Moss.
1882. Southampton.	Rt. Hon. G. Sclater-Booth, M.P., F.R.S.	G. Baden Powell, Prof. H. S. Foxwell, A. Milnes, C. Molloy.

MECHANICAL SCIENCE.

SECTION G.—MECHANICAL SCIENCE.

1836. Bristol......	Davies Gilbert, D.C.L., F.R.S.	T. G. Bunt, G. T. Clark, W. West.
1837. Liverpool...	Rev. Dr. Robinson	Charles Vignoles, Thomas Webster.
1838. Newcastle	Charles Babbage, F.R.S.......	R. Hawthorn, C. Vignoles, T. Webster.
1839. Birmingham	Prof. Willis, F.R.S., and Robt. Stephenson.	W. Carpmael, William Hawkes, T. Webster.
1840. Glasgow	Sir John Robinson	J. Scott Russell, J. Thomson, J. Tod, C. Vignoles.
1841. Plymouth	John Taylor, F.R.S.	Henry Chatfield, Thomas Webster.
1842. Manchester	Rev. Prof. Willis, F.R.S.......	J. F. Bateman, J. Scott Russell, J. Thomson, Charles Vignoles.
1843. Cork.........	Prof. J. Macneill, M.R.I.A....	James Thomson, Robert Mallet.
1844. York.........	John Taylor, F.R.S.	Charles Vignoles, Thomas Webster.
1845. Cambridge	George Rennie, F.R.S.	Rev. W. T. Kingsley.
1846. Southampton.	Rev. Prof. Willis, M.A., F.R.S.	William Betts, jun., Charles Manby.
1847. Oxford......	Rev. Professor Walker, M.A., F.R.S.	J. Glynn, R. A. Le Mesurier.
1848. Swansea ...	Rev. Professor Walker, M.A., F.R.S.	R. A. Le Mesurier, W. P. Struvé
1849. Birmingham	Robert Stephenson, M.P., F.R.S.	Charles Manby, W. P. Marshall.
1850. Edinburgh	Rev. R. Robinson	Dr. Lees, David Stephenson.
1851. Ipswich	William Cubitt, F.R.S..........	John Head, Charles Manby.
1852. Belfast......	John Walker, C.E., LL.D., F.R.S.	John F. Bateman, C. B. Hancock, Charles Manby, James Thomson.
1853. Hull.........	William Fairbairn, C.E., F.R.S.	James Oldham, J. Thomson, W. Sykes Ward.
1854. Liverpool...	John Scott Russell, F.R.S.	John Grantham, J. Oldham, J. Thomson.
1855. Glasgow ...	W. J. Macquorn Rankine, C.E., F.R.S.	L. Hill, jun., William Ramsay, J. Thomson.
1856. Cheltenham	George Rennie, F.R.S.	C. Atherton, B. Jones, jun., H. M. Jeffery.
1857. Dublin......	Rt. Hon. the Earl of Rosse, F.R.S.	Prof. Downing, W.T. Doyne, A. Tate, James Thomson, Henry Wright.
1858. Leeds	William Fairbairn, F.R.S. ...	J. C. Dennis, J. Dixon, H. Wright.
1859. Aberdeen...	Rev. Prof. Willis, M.A., F.R.S.	R. Abernethy, P. Le Neve Foster, H. Wright.
1860. Oxford	Prof. W. J. Macquorn Rankine, LL.D., F.R.S.	P. Le Neve Foster, Rev. F. Harrison, Henry Wright.
1861. Manchester	J. F. Bateman, C.E., F.R.S....	P. Le Neve Foster, John Robinson, H. Wright.
1862. Cambridge	Wm. Fairbairn, LL.D., F.R.S.	W. M. Fawcett, P. Le Neve Foster.

Date and Place	Presidents	Secretaries
1863. Newcastle	Rev. Prof. Willis, M.A., F.R.S.	P. Le Neve Foster, P. Westmacott, J. F. Spencer.
1864. Bath	J. Hawkshaw, F.R.S.	P. Le Neve Foster, Robert Pitt.
1865. Birmingham	Sir W. G. Armstrong, LL.D., F.R.S.	P. Le Neve Foster, Henry Lea, W. P. Marshall, Walter May.
1866. Nottingham	Thomas Hawksley, V.P.Inst. C.E., F.G.S.	P. Le Neve Foster, J. F. Iselin, M. O. Tarbotton.
1867. Dundee......	Prof. W. J. Macquorn Rankine, LL.D., F.R.S.	P. Le Neve Foster, John P. Smith, W. W. Urquhart.
1868. Norwich ...	G. P. Bidder, C.E., F.R.G.S.	P. Le Neve Foster, J. F. Iselin, C. Manby, W. Smith.
1869. Exeter	C. W. Siemens, F.R.S.........	P. Le Neve Foster, H. Bauerman.
1870. Liverpool...	Chas. B. Vignoles, C.E., F.R.S.	H. Bauerman, P. Le Neve Foster, T. King, J. N. Shoolbred.
1871. Edinburgh	Prof. Fleeming Jenkin, F.R.S.	H. Bauerman, Alexander Leslie, J. P. Smith.
1872. Brighton ...	F. J. Bramwell, C.E.	H. M. Brunel, P. Le Neve Foster, J. G. Gamble, J. N. Shoolbred.
1873. Bradford ...	W. H. Barlow, F.R.S.	Crawford Barlow, H. Bauerman, E. H. Carbutt, J. C. Hawkshaw, J. N. Shoolbred.
1874. Belfast......	Prof. James Thomson, LL.D., C.E., F.R.S.E.	A. T. Atchison, J. N. Shoolbred, John Smyth, jun.
1875. Bristol	W. Froude, C.E., M.A., F.R.S.	W. R. Browne, H. M. Brunel, J. G. Gamble, J. N. Shoolbred.
1876. Glasgow ...	C. W. Merrifield, F.R.S.	W. Bottomley, jun., W. J. Millar, J. N. Shoolbred, J. P. Smith.
1877. Plymouth...	Edward Woods, C.E.	A. T. Atchison, Dr. Merrifield, J. N. Shoolbred.
1878. Dublin	Edward Easton, C.E.	A. T. Atchison, R. G. Symes, H. T. Wood.
1879. Sheffield ...	J. Robinson, Pres. Inst. Mech. Eng.	A. T. Atchison, Emerson Bainbridge, H. T. Wood.
1880. Swansea ...	James Abernethy, V.P. Inst. C.E., F.R.S.E.	A. T. Atchison, H. T. Wood.
1881. York.........	Sir W. G. Armstrong, C.B., LL.D., D.C.L., F.R.S.	A. T. Atchison, J. F. Stephenson, H. T. Wood.
1882. Southampton.	John Fowler, C.E., F.G.S. ...	A. T. Atchison, F. Churton, H. T. Wood.

List of Evening Lectures.

Date and Place	Lecturer	Subject of Discourse
1842. Manchester	Charles Vignoles, F.R.S......	The Principles and Construction of Atmospheric Railways.
	Sir M. I. Brunel	The Thames Tunnel.
	R. I. Murchison.................	The Geology of Russia.
1843. Cork	Prof. Owen, M.D., F.R.S.......	The Dinornis of New Zealand.
	Prof. E. Forbes, F.R.S..........	The Distribution of Animal Life in the Ægean Sea.
	Dr. Robinson......................	The Earl of Rosse's Telescope.
1844. York	Charles Lyell, F.R.S.	Geology of North America.
	Dr. Falconer, F.R.S............	The Gigantic Tortoise of the Siwalik Hills in India.
1845. Cambridge	G. B. Airy, F.R.S., Astron. Royal	Progress of Terrestrial Magnetism.
	R. I. Murchison, F.R.S.	Geology of Russia.

Date and Place	Lecturer	Subject of Discourse
1846. Southampton.	Prof. Owen, M.D., F.R.S. ...	Fossil Mammalia of the British Isles.
	Charles Lyell, F.R.S.	Valley and Delta of the Mississippi.
	W. R. Grove, F.R.S.	Properties of the Explosive substance discovered by Dr. Schönbein; also some Researches of his own on the Decomposition of Water by Heat.
1847. Oxford	Rev. Prof. B. Powell, F.R.S.	Shooting Stars.
	Prof. M. Faraday, F.R.S.	Magnetic and Diamagnetic Phenomena.
	Hugh E. Strickland, F.G.S.	The Dodo (*Didus ineptus*).
1848. Swansea ...	John Percy, M.D., F.R.S.	Metallurgical Operations of Swansea and its neighbourhood.
	W. Carpenter, M.D., F.R.S. ...	Recent Microscopical Discoveries.
1849. Birmingham	Dr. Faraday, F.R.S	Mr. Gassiot's Battery.
	Rev. Prof. Willis, M.A., F.R.S.	Transit of different Weights with varying velocities on Railways.
1850. Edinburgh	Prof. J. H. Bennett, M.D., F.R.S.E.	Passage of the Blood through the minute vessels of Animals in connexion with Nutrition.
	Dr. Mantell, F.R.S.	Extinct Birds of New Zealand.
1851. Ipswich ...	Prof. R. Owen, M.D., F.R.S.	Distinction between Plants and Animals, and their changes of Form.
	G.B.Airy, F.R.S., Astron. Royal	Total Solar Eclipse of July 28, 1851.
1852. Belfast	Prof. G. G. Stokes, D.C.L., F.R.S.	Recent discoveries in the properties of Light.
	Colonel Portlock, R.E., F.R.S.	Recent discovery of Rock-salt at Carrickfergus, and geological and practical considerations connected with it.
1853. Hull	Prof. J. Phillips, LL.D., F.R.S., F.G.S.	Some peculiar Phenomena in the Geology and Physical Geography of Yorkshire.
	Robert Hunt, F.R.S.	The present state of Photography.
1854. Liverpool...	Prof. R. Owen, M.D., F.R.S.	Anthropomorphous Apes.
	Col. E. Sabine, V.P.R.S.	Progress of researches in Terrestrial Magnetism.
1855. Glasgow ...	Dr. W. B. Carpenter, F.R.S.	Characters of Species.
	Lieut.-Col. H. Rawlinson ...	Assyrian and Babylonian Antiquities and Ethnology.
1856. Cheltenham	Col. Sir H. Rawlinson	Recent Discoveries in Assyria and Babylonia, with the results of Cuneiform research up to the present time.
	W. R. Grove, F.R.S.	Correlation of Physical Forces.
1857. Dublin	Prof. W. Thomson, F.R.S ...	The Atlantic Telegraph.
	Rev. Dr. Livingstone, D.C.L.	Recent Discoveries in Africa.
1858. Leeds	Prof. J. Phillips, LL.D., F.R.S.	The Ironstones of Yorkshire.
	Prof. R. Owen, M.D., F.R.S.	The Fossil Mammalia of Australia.
1859. Aberdeen...	Sir R. I. Murchison, D.C.L....	Geology of the Northern Highlands.
	Rev. Dr. Robinson, F.R.S. ...	Electrical Discharges in highly rarefied Media.
1860. Oxford	Rev. Prof. Walker, F.R.S. ...	Physical Constitution of the Sun.
	Captain Sherard Osborn, R.N.	Arctic Discovery.
1861. Manchester	Prof. W. A. Miller, M.A., F.R.S.	Spectrum Analysis.
	G.B.Airy, F.R.S., Astron. Royal	The late Eclipse of the Sun.
1862. Cambridge	Prof. Tyndall, LL.D., F.R.S.	The Forms and Action of Water.
	Prof. Odling, F.R.S.	Organic Chemistry.
1863. Newcastle	Prof. Williamson, F.R.S.	The Chemistry of the Galvanic Battery considered in relation to Dynamics.

Date and Place	Lecturer	Subject of Discourse
1863. Newcastle (*cont.*)	James Glaisher, F.R.S.	The Balloon Ascents made for the British Association.
1864. Bath	Prof. Roscoe, F.R.S.	The Chemical Action of Light.
	Dr. Livingstone, F.R.S.	Recent Travels in Africa.
1865. Birmingham	J. Beete Jukes, F.R.S.	Probabilities as to the position and extent of the Coal-measures beneath the red rocks of the Midland Counties.
1866. Nottingham	William Huggins, F.R.S.	The results of Spectrum Analysis applied to Heavenly Bodies.
	Dr. J. D. Hooker, F.R.S.	Insular Floras.
1867. Dundee	Archibald Geikie, F.R.S.	The Geological Origin of the present Scenery of Scotland.
	Alexander Herschel, F.R.A.S.	The present state of knowledge regarding Meteors and Meteorites.
1868. Norwich	J. Fergusson, F.R.S.	Archæology of the early Buddhist Monuments.
	Dr. W. Odling, F.R.S.	Reverse Chemical Actions.
1869. Exeter	Prof. J. Phillips, LL.D., F.R.S.	Vesuvius.
	J. Norman Lockyer, F.R.S.	The Physical Constitution of the Stars and Nebulæ.
1870. Liverpool	Prof. J. Tyndall, LL.D., F.R.S.	The Scientific Use of the Imagination.
	Prof. W. J. Macquorn Rankine, LL.D., F.R.S.	Stream-lines and Waves, in connection with Naval Architecture.
1871. Edinburgh	F. A. Abel, F.R.S.	Some recent investigations and applications of Explosive Agents.
	E. B. Tylor, F.R.S.	The Relation of Primitive to Modern Civilization.
1872. Brighton	Prof. P. Martin Duncan, M.B., F.R.S.	Insect Metamorphosis.
	Prof. W. K. Clifford	The Aims and Instruments of Scientific Thought.
1873. Bradford	Prof. W. C. Williamson, F.R.S.	Coal and Coal Plants.
	Prof. Clerk Maxwell, F.R.S.	Molecules.
1874. Belfast	Sir John Lubbock, Bart., M.P., F.R.S.	Common Wild Flowers considered in relation to Insects.
	Prof. Huxley, F.R.S.	The Hypothesis that Animals are Automata, and its History.
1875. Bristol	W. Spottiswoode, LL.D., F.R.S.	The Colours of Polarized Light.
	F. J. Bramwell, F.R.S.	Railway Safety Appliances.
1876. Glasgow	Prof. Tait, F.R.S.E.	Force.
	Sir Wyville Thomson, F.R.S.	The *Challenger* Expedition.
1877. Plymouth	W. Warington Smyth, M.A., F.R.S.	The Physical Phenomena connected with the Mines of Cornwall and Devon.
	Prof. Odling, F.R.S.	The new Element, Gallium.
1878. Dublin	G. J. Romanes, F.L.S.	Animal Intelligence.
	Prof. Dewar, F.R.S.	Dissociation, or Modern Ideas of Chemical Action.
1879. Sheffield	W. Crookes, F.R.S.	Radiant Matter.
	Prof. E. Ray Lankester, F.R.S.	Degeneration.
1880. Swansea	Prof. W. Boyd Dawkins, F.R.S.	Primeval Man.
	Francis Galton, F.R.S.	Mental Imagery.
1881. York	Prof. Huxley, Sec. R.S.	The Rise and Progress of Palæontology.
	W. Spottiswoode, Pres. R.S.	The Electric Discharge, its Forms and its Functions.
1882. Southampton.	Prof. Sir Wm. Thomson, F.R.S.	Tides.
	Prof. H. N. Moseley, F.R.S.	Pelagic Life.

Lectures to the Operative Classes.

Date and Place	Lecturer	Subject of Discourse
1867. Dundee......	Prof. J. Tyndall, LL.D., F.R.S.	Matter and Force.
1868. Norwich ...	Prof. Huxley, LL.D., F.R.S.	A Piece of Chalk.
1869. Exeter	Prof. Miller, M.D., F.R.S. ...	Experimental illustrations of the modes of detecting the Composition of the Sun and other Heavenly Bodies by the Spectrum.
1870. Liverpool...	Sir John Lubbock, Bart., M.P., F.R.S.	Savages.
1872. Brighton ...	W. Spottiswoode, LL.D., F.R.S.	Sunshine, Sea, and Sky.
1873. Bradford ...	C. W. Siemens, D.C.L., F.R.S.	Fuel.
1874. Belfast	Prof. Odling, F.R.S............	The Discovery of Oxygen.
1875. Bristol	Dr. W. B. Carpenter, F.R.S.	A Piece of Limestone.
1876. Glasgow ...	Commander Cameron, C.B., R.N.	A Journey through Africa.
1877. Plymouth...	W. H. Preece.....................	Telegraphy and the Telephone.
1879. Sheffield ...	W. E. Ayrton	Electricity as a Motive Power.
1880. Swansea ...	H. Seebohm, F Z.S.	The North-East Passage.
1881. York.........	Prof. Osborne Reynolds, F.R S.	Raindrops, Hailstones, and Snowflakes.
1882. Southampton.	John Evans, D.C.L. Treas. R.S.	Unwritten History, and how to read it.

OFFICERS OF SECTIONAL COMMITTEES PRESENT AT THE SOUTHAMPTON MEETING.

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President.—Right Hon. Professor Lord Rayleigh, M.A., F.R.S.

Vice-Presidents.—G. H. Darwin, M.A., F.R.S.; Professor W. G. Adams, M.A., F.R.S.; Dr. Werner Siemens; J. W. L. Glaisher, M.A., F.R.S.; W. Spottiswoode, D.C.L., Pres. R.S.; Professor Cayley, F.R.S.; Sir W. Thomson, D.C.L., F.R.S.

Secretaries.—W. M. Hicks, M.A.; Professor O. J. Lodge, D.Sc.; D. McAlister, M.A., M.B., B.Sc. (*Recorder*); Rev. G. Richardson, M.A.

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Professor J. D. Macdonald, M.D., F.R.S.; Professor Moseley, F.R.S.; P. L. Sclater, F.R.S.; Dr. Allen Thomson, F.R.S.; Professor Du Bois-Reymond.

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President.—John Fowler, C.E., F.G.S.

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Secretaries.—A. T. Atchison, M.A.; F. Churton; H. T. Wood, B.A. (*Recorder*).

Table showing the Attendance and Receipts

Date of Meeting	Where held	Presidents	Old Life Members	New Life Members
1831, Sept. 27 ...	York	The Earl Fitzwilliam, D.C.L.	...	...
1832, June 19 ...	Oxford	The Rev. W. Buckland, F.R.S.	...	...
1833, June 25 ...	Cambridge	The Rev. A. Sedgwick, F.R.S.	...	...
1834, Sept. 8 ...	Edinburgh	Sir T. M. Brisbane, D.C.L.......	...	...
1835, Aug. 10 ...	Dublin	The Rev. Provost Lloyd, LL.D.	...	...
1836, Aug. 22 ...	Bristol	The Marquis of Lansdowne ...	...	...
1837, Sept. 11 ...	Liverpool	The Earl of Burlington, F.R.S.	...	...
1838, Aug. 10 ...	Newcastle-on-Tyne	The Duke of Northumberland	...	...
1839, Aug. 26 ...	Birmingham.........	The Rev. W. Vernon Harcourt	...	...
1840, Sept. 17 ...	Glasgow	The Marquis of Breadalbane...	...	...
1841, July 20 ...	Plymouth	The Rev. W. Whewell, F.R.S.	169	65
1842, June 23 ...	Manchester	The Lord Francis Egerton......	303	169
1843, Aug. 17 ...	Cork	The Earl of Rosse, F.R.S.......	109	28
1844, Sept. 26 ...	York	The Rev. G. Peacock, D.D. ...	226	150
1845, June 19 ...	Cambridge	Sir John F. W. Herschel, Bart.	313	36
1846, Sept. 10 ...	Southampton	Sir Roderick I. Murchison, Bart.	241	10
1847, June 23 ...	Oxford	Sir Robert H. Inglis, Bart.......	314	18
1848, Aug. 9 ...	Swansea	The Marquis of Northampton	149	3
1849, Sept. 12 ...	Birmingham.........	The Rev. T. R. Robinson, D.D.	227	12
1850, July 21 ...	Edinburgh	Sir David Brewster, K.H.	235	9
1851, July 2 ...	Ipswich	G. B. Airy, Astronomer Royal	172	8
1852, Sept. 1 ...	Belfast	Lieut.-General Sabine, F.R.S.	164	10
1853, Sept. 3 ...	Hull	William Hopkins, F.R.S.	141	13
1854, Sept. 20 ...	Liverpool	The Earl of Harrowby, F.R.S.	238	23
1855, Sept. 12 ...	Glasgow	The Duke of Argyll, F.R.S. ...	194	33
1856, Aug. 6 ...	Cheltenham	Prof. C. G. B. Daubeny, M.D.	182	14
1857, Aug. 26 ...	Dublin	The Rev. Humphrey Lloyd, D.D.	236	15
1858, Sept. 22 ...	Leeds..................	Richard Owen, M.D., D.C.L....	222	42
1859, Sept. 14 ...	Aberdeen	H.R.H. the Prince Consort ...	184	27
1860, June 27 ...	Oxford	The Lord Wrottesley, M.A. ..	286	21
1861, Sept. 4	Manchester	William Fairbairn, LL.D., F.R.S.	321	113
1862, Oct. 1 ...	Cambridge	The Rev. Professor Willis, M.A.	239	15
1863, Aug. 26 ...	Newcastle-on-Tyne	Sir William G. Armstrong, C.B.	203	36
1864, Sept. 13 ...	Bath	Sir Charles Lyell, Bart., M.A.	287	40
1865, Sept. 6 ...	Birmingham.........	Prof. J. Phillips, M.A., LL.D.	292	44
1866, Aug. 22 ...	Nottingham	William R. Grove, Q.C., F.R.S.	207	31
1867, Sept. 4 ...	Dundee	The Duke of Buccleuch, K.C.B.	167	25
1868, Aug. 19 ...	Norwich	Dr. Joseph D. Hooker, F.R.S.	196	18
1869, Aug. 18 ...	Exeter	Prof. G. G. Stokes, D.C.L.......	204	21
1870, Sept. 14 ...	Liverpool	Prof. T. H. Huxley, LL.D.......	314	39
1871, Aug. 2 ...	Edinburgh	Prof. Sir W. Thomson, LL.D.	246	28
1872, Aug. 14 ...	Brighton	Dr. W. B. Carpenter, F.R.S. ...	245	36
1873, Sept. 17 ...	Bradford	Prof. A. W. Williamson, F.R.S.	212	27
1874, Aug. 19 ...	Belfast	Prof. J. Tyndall, LL.D., F.R.S.	162	13
1875, Aug. 25 ...	Bristol	Sir John Hawkshaw, C.E., F.R.S.	239	36
1876, Sept. 6 ...	Glasgow	Prof. T. Andrews, M.D., F.R.S.	221	35
1877, Aug. 15 ...	Plymouth	Prof. A. Thomson, M.D., F.R.S.	173	19
1878, Aug. 14 ...	Dublin	W. Spottiswoode, M.A., F.R.S.	201	18
1879, Aug. 20 ...	Sheffield	Prof. G. J. Allman, M.D., F.R.S.	184	16
1880, Aug. 25 ...	Swansea	A. C. Ramsay, LL.D., F.R.S....	144	11
1881, Aug. 31 ...	York	Sir John Lubbock, Bart., F.R.S.	272	28
1882, Aug. 23 ...	Southampton	Dr. C. W. Siemens, F.R.S.......	178	17

at Annual Meetings of the Association.

Attended by						Amount received during the Meeting	Sums paid on Account of Grants for Scientific Purposes	Year
Old Annual Members	New Annual Members	Associates	Ladies	Foreigners	Total	£ s. d.	£ s. d.	
...	...	...	...	...	353	....	....	1831
...	...	...	...	...	...	....	....	1832
...	...	...	...	...	900	....	....	1833
...	...	...	...	...	1298	....	20 0 0	1834
...	...	...	...	...	...	....	167 0 0	1835
...	...	...	...	...	1350	....	435 0 0	1836
...	...	...	...	...	1840	....	922 12 6	1837
...	...	...	1100*	...	2400	....	932 2 2	1838
...	...	...	...	34	1438	....	1595 11 0	1839
...	...	...	...	40	1353	....	1546 16 4	1840
46	317	...	60*	...	891	....	1235 10 11	1841
75	376	33†	331*	28	1315	....	1449 17 8	1842
71	185	...	160	...	...	....	1565 10 2	1843
45	190	9†	260	...	...	....	981 12 8	1844
94	22	407	172	35	1079	....	831 9 9	1845
65	39	270	196	36	857	....	685 16 0	1846
197	40	495	203	53	1320	....	208 5 4	1847
54	25	376	197	15	819	707 0 0	275 1 8	1848
93	33	447	237	22	1071	963 0 0	159 19 6	1849
128	42	510	273	44	1241	1085 0 0	345 18 0	1850
61	47	244	141	37	710	620 0 0	391 9 7	1851
63	60	510	292	9	1108	1085 0 0	304 6 7	1852
56	57	367	236	6	876	903 0 0	205 0 0	1853
121	121	765	524	10	1802	1882 0 0	380 19 7	1854
142	101	1094	543	26	2133	2311 0 0	480 16 4	1855
104	48	412	346	9	1115	1098 0 0	734 13 9	1856
156	120	900	569	26	2022	2015 0 0	507 15 4	1857
111	91	710	509	13	1698	1931 0 0	618 18 2	1858
125	179	1206	821	22	2564	2782 0 0	684 11 1	1859
177	59	636	463	47	1689	1604 0 0	766 19 6	1860
184	125	1589	791	15	3138	3944 0 0	1111 5 10	1861
150	57	433	242	25	1161	1089 0 0	1293 16 6	1862
154	209	1704	1004	25	3335	3640 0 0	1608 3 10	1863
182	103	1119	1058	13	2802	2965 0 0	1289 15 8	1864
215	149	766	508	23	1997	2227 0 0	1591 7 10	1865
218	105	960	771	11	2303	2469 0 0	1750 13 4	1866
193	118	1163	771	7	2444	2613 0 0	1739 4 0	1867
226	117	720	682	45‡	2004	2042 0 0	1940 0 0	1868
229	107	678	600	17	1856	1931 0 0	1622 0 0	1869
303	195	1103	910	14	2878	3096 0 0	1572 0 0	1870
311	127	976	754	21	2463	2575 0 0	1472 2 6	1871
280	80	937	912	43	2533	2649 0 0	1285 0 0	1872
237	99	796	601	11	1983	2120 0 0	1685 0 0	1873
232	85	817	630	12	1951	1979 0 0	1151 16 0	1874
307	93	884	672	17	2248	2397 0 0	960 0 0	1875
331	185	1265	712	25	2774	3023 0 0	1092 4 2	1876
238	59	446	283	11	1229	1268 0 0	1128 9 7	1877
290	93	1285	674	17	2578	2615 0 0	725 16 6	1878
239	74	529	349	13	1404	1425 0 0	1080 11 11	1879
171	41	389	147	12	915	899 0 0	731 7 7	1880
313	176	1230	514	24	2557	2689 0 0	476 3 1	1881
253	79	516	189	21	1253	1286 0 0	1126 1 11	1882

* Ladies were not admitted by purchased Tickets until 1843.
† Tickets of Admission to Sections only. ‡ Including Ladies.

THE GENERAL TREASURER'S ACCOUNT from August 31, 1881 (commencement of York Meeting), to August 23, 1882. (Not including receipts at Southampton Meeting.)

1881–82. RECEIPTS.	£	s.	d.
By Balance of last Account, York Meeting	88	18	6
Received for Life Compositions at York Meeting and since	350	0	0
" Annual Subscriptions ditto ditto	825	0	0
" Associates' Tickets at York Meeting	1232	0	0
" Ladies' Tickets ditto	514	0	0
" Dividends on Stock	249	13	10
" Sale of Publications	157	18	0
Received for Rent from Mathematical Society, year ending Michaelmas, 1881	12	15	0
	£3430	5	4

1881–82. PAYMENTS.					£	s.	d.
By paid Expenses of York Meeting, also Sundry Printing, Binding, Advertising, and Incidental Expenses					310	10	7
" Messrs. Spottiswoode & Co.'s account for printing—1881–82—Report of 51st Meeting, Vol. L.					762	14	3
" Salaries (1 year)					688	15	0
" Rent of Office (22 Albemarle Street—1 year)					117	0	0
" Grants made at York Meeting:—	£	s.	d.				
1881. Oct. 1. Tertiary Flora of North of Ireland	20	0	0				
" 26. Exploration of Caves of South of Ireland	10	0	0				
" 26. Fossil Plants of Halifax	15	0	0				
Nov. 5. July 5. Fundamental Invariants of Algebraical Forms	76	1	11				
Nov. 2. Record of Zoological Literature	100	0	0				
" 16. British Fossil Polyzoa	10	0	0				
" 18. Naples Zoological Station	80	0	0				
" 29. Natural History of Timor-laut	100	0	0				
1882. Jan. 10. Conversion of Sedimentary Materials into Metamorphic Rocks	10	0	0				
" 14. Natural History of Socotra	100	0	0				
Feb. 10. Circulation of Underground Waters	15	0	0				
" 16. Migration of Birds	15	0	0				
" 17. Earthquake Phenomena of Japan	25	0	0				
" 17. Geological Map of Europe	25	0	0				
March 11. Elimination of Nitrogen by Bodily Exercise	50	0	0				
June 2. Anthropometric Committee	50	0	0				
" 8. Photographing Ultra-Violet Spark Spectra	25	0	0				
July 5. Exploration of Raygill Fissure	20	0	0				
" 8. Calibration of Mercurial Thermometers	20	0	0				
" 13. Wave-lengths Tables of Spectra of Elements	50	0	0				
" 27. Geological Record	100	0	0				
" 31. Standards for Electrical Measurements	100	0	0				
" 31. Exploration of Central Africa	100	0	0				
Aug. 9. Albuminoid Substances of Serum	10	0	0				
					1126	1	11
Balance at Bank of England, Western Branch					425	3	7
					£3430	5	4

ALEX. W. WILLIAMSON.

G. CAREY FOSTER,
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Auditors.

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Professor T. G. BONNEY, M.A., F.R.S., F.S.A., F.G.S., 22 Albemarle Street, London, W.

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REPORT OF THE COUNCIL.

Report of the Council for the year 1881–82, *presented to the General Committee at Southampton, on Wednesday, August* 23, 1882.

The Council have received reports during the past year from the General Treasurer, and his account for the year will be laid before the General Committee this day.

Since the meeting at York the following have been elected Corresponding Members of the Association:—

Barker, Professor G. F.	Johnson, Professor W. W.
Cooke, Professor J. P.	Marsh, Professor O. C.
Eads, Captain J. B.	Rowland, Professor H. A.
Gariel, M.	Stephanos, M.
Halphen, M.	Sturm, Professor.
Hall, Dr. E. H.	Whitney, Professor H. M.
Hubrecht, Dr. A. A. W.	

It is with the deepest regret that the Council announce the untimely death of Professor F. M. Balfour, F.R.S., so lately appointed a General Secretary. In him science has lost a student of rare genius and unwearied industry, the Association one who would have served it well and ably.

In respect of the Resolution referred by the General Committee:—'That the Council be requested to consider the number and position of delegates from Scientific Societies, and the regulations which should be adopted for governing their relations to the Association,' the Council beg leave to make the following recommendations to the General Committee:—(1) The omission in the rules (General Committee, Class B Temporary Members § 1) of the words 'and the Secretary of such Society' which follow the words 'or, in his absence, a delegate representing him.' (2) The appointment of a Committee in order to draw up suggestions upon methods of more systematic observation and plans of operation for local societies, together with a more uniform mode of publication of the results of their work. It is recommended that this Committee should draw up a list of local societies which publish their proceedings.

Upon the resolution of the General Committee requesting the Council consider how far it may be expedient to take steps to ascertain the ˈng of foreign Scientific Associations as to the advisability of holding nternational Scientific Congress, the Council have to report that recognising the difficulties which will attend the endeavour they ıend that steps be taken to ascertain the feeling of foreign ˈc Associations, similar in character to the British Association,

upon this question, and they request authority to make the necessary communications to foreign Societies.

In regard to the resolution of the General Committee empowering the Council to confer with the Royal Geographical Society on the subject of the Exploration of the Snowy Mountain Range of Eastern Equatorial Africa, and to contribute the sum of 100*l.* towards the expenses of an expedition, the Council have been informed by the Council of the Royal Geographical Society, in a letter dated June 26, that they have decided upon undertaking the expedition, and have secured the services of the well-known and experienced explorer, Mr. Thomson; the Treasurer has accordingly paid the above-named contribution.

An invitation to visit Canada in 1883, warmly supported by the Governor-General, His Excellency the Marquis of Lorne, was received at the end of last year, but the Council were obliged to reply that the vote of the General Committee at York accepting the invitation to Oxford precluded them from entertaining the question for that year. With reference, however, to the Meeting for 1883, the Council regret to inform the General Committee that unforeseen difficulties have recently obliged their intended hosts at Oxford to express a desire that the proposed visit of the Association should be for a time postponed. Under these circumstances Southport and Birmingham have renewed their invitation for 1883, and invitations for 1884 have been received from Birmingham, Southport, Aberdeen, and Nottingham.

The Council propose that, in accordance with the regulations, the five retiring members shall be the following:—

Mr. Abel.
Mr. J. Evans.
Professor G. C. Foster.
Professor Newton.
General Pitt-Rivers.

The Council recommend the re-election of the other ordinary members of the Council, with the addition of those whose names are distinguished by an asterisk in the following list:—

Adams, Professor W. G., F.R.S.
Bateman, J. F., Esq., C.E., F.R.S.
Cayley, Professor, F.R.S.
*Darwin, F., Esq., F.R.S.
*Dawkins, Professor W. Boyd, F.R.S.
De la Rue, Warren, Esq., F.R.S.
Evans, Captain Sir F. J., K.C.B., F.R.S.
*Flower, Professor W. H., F.R.S.
*Gladstone, Dr. J. H., F.R.S.
Glaisher, J. W. L., Esq., F.R.S.
Harcourt, A. G. Vernon, Esq., F.R.S.
Hastings, G. W., Esq., M.P.
Hawkshaw, J. Clarke, Esq., F.G.S.
Heywood, J., Esq., F.R.S.
Huggins, W., Esq., F.R.S.
Hughes, Professor T. McK., F.G.S.
Jeffreys, Dr. J. Gwyn, F.R.S.
Pengelly, W., Esq., F.R.S.
Perkin, W. H., Esq., F.R.S.
Prestwich, Professor J., F.R.S.
Rayleigh, Lord, F.R.S.
Sanderson, Professor J. S. Burdon, F.R.S.
*Smith, Professor H. J. S., F.R.S.
Sorby, Dr. H. C., F.R.S.
Thuillier, General Sir H. E. L., C.S.I., F.R.S.

Recommendations adopted by the General Committee at the Southampton Meeting in August 1882.

[When Committees are appointed, the Member first named is regarded as the Secretary, except there is a specific nomination.]

Involving Grants of Money.

That Professor Crum Brown, Mr. Milne-Home, Mr. John Murray, and Mr. Buchan be a Committee for the purpose of co-operating with the Scottish Meteorological Society in making meteorological observations on Ben Nevis; that Professor Crum Brown be the Secretary, and that the sum of 50*l*. be placed at their disposal for the purpose.

That Mr. Robert H. Scott, Mr. J. Norman Lockyer, Professor H. J. S. Smith, Professor G. G. Stokes, Professor Balfour Stewart, and Mr. G. J. Symons be reappointed a Committee for the purpose of co-operating with the Meteorological Society of the Mauritius in their proposed publication of Daily Synoptic Charts of the Indian Ocean from the year 1861; that Mr. R. H. Scott be the Secretary, and that the unexpended sum of 50*l*. be again placed at their disposal for the purpose.

That Mr. G. H. Darwin and Professor J. C. Adams be a Committee for the Harmonic Analysis of Tidal Observations; that Mr. Darwin be the Secretary, and that the sum of 50*l*. be placed at their disposal for the purpose.

That Professors W. A. Tilden and H. E. Armstrong be a Committee for the purpose of investigating Isomeric Naphthalene Derivatives; that Professor H. E. Armstrong be the Secretary, and that the sum of 15*l*. be placed at their disposal for the purpose.

That Professors Odling, Huntington, and Hartley be a Committee for the purpose of investigating by means of Photography the Ultra-Violet Spark-Spectra emitted by Metallic Elements and their combinations under varying conditions; that Professor W. N. Hartley be the Secretary, and that the sum of 20*l*. be placed at their disposal for the purpose.

That Mr. R. Etheridge, Mr. Thomas Gray, and Professor John Milne be a Committee for the purpose of investigating the Earthquake Phenomena of Japan; that Professor J. Milne be the Secretary, and that the sum of 50*l*. be placed at their disposal for the purpose.

That Professor W. C. Williamson, Mr. Thos. Hick, and Mr. W. Cash be a Committee for the purpose of investigating the Fossil Plants of Halifax; that Mr. W. Cash be the Secretary, and that the sum of 20*l*. be placed at their disposal for the purpose.

That Dr. H. C. Sorby and Mr. G. R. Vine be a Committee for the purpose of reporting on the British Fossil Polyzoa; that Mr. Vine be the Secretary, and that the sum of 10*l*. be placed at their disposal for the purpose.

That Mr. R. Etheridge, Dr. H. Woodward, and Professor T. R. Jones

be a Committee for the purpose of reporting on the Fossil Phyllopoda of the Palæozoic Rocks; that Professor T. R. Jones be the Secretary, and that the sum of 25*l.* be placed at their disposal for the purpose.

That Sir John Hawkshaw, and Messrs. R. B. Grantham, J. B. Redman, J. W. Woodall, W. Whitaker, W. Topley, and C. E. De Rance be a Committee for the purpose of inquiring into the rate of Erosion of the Sea-coasts of England and Wales, and the influence of the Artificial abstraction of shingle and other material in that action; that Messrs. W. Topley and C. E. De Rance be the Secretaries, and that the sum of 10*l.* be placed at their disposal for the purpose.

That Professor E. Hull, the Rev. H. W. Crosskey, Captain Douglas Galton, Professors G. A. Lebour and J. Prestwich, and Messrs. James Glaisher, E. B. Marten, W. Molyneux, G. H. Morton, James Parker, W. Pengelly, James Plant, I. Roberts, Fox Strangways, T. S. Stooke, G. J. Symons, W. Topley, Tylden-Wright, E. Wethered, W. Whitaker, and C. E. De Rance be a Committee for the purpose of investigating the Circulation of the Underground Waters in the Permeable Formations of England, and the Quality and Quantity of the Waters supplied to various towns and districts from these formations; that Mr. C. E. De Rance be the Secretary, and that the sum of 15*l.* be placed at their disposal for the purpose.

That Dr. J. Evans, Professor J. F. Blake, and Messrs. W. Carruthers, F. Drew, F. W. Rudler, E. B. Tawney, W. Topley, E. Wethered, and W. Whitaker be a Committee for the purpose of carrying on the Geological Record; that Mr. Whitaker be the Secretary, and that the sum of 50*l.* be placed at their disposal for the purpose.

That Professor V. Ball, Professor W. Boyd Dawkins, Dr. J. Evans, Mr. G. H. Kinahan, and Mr. R. J. Ussher be a Committee for the purpose of carrying out Explorations in Caves in the Carboniferous Limestone of the South of Ireland; that Mr. R. J. Ussher be the Secretary, and that the sum of 20*l.* be placed at their disposal for the purpose.

That Mr. R. Etheridge and Mr. Walter Keeping be a Committee for the purpose of reporting on the Llandovery Rocks of Central Wales; that Mr. W. Keeping be the Secretary, and that the sum of 10*l.* be placed at their disposal for the purpose.

That General Pitt-Rivers, Professor Flower, Dr. Beddoe, Mr. Brabrook, Mr. F. Galton, Mr. J. Park Harrison, Dr. Muirhead, Mr. F. W. Rudler, and Mr. Charles Roberts be a Committee for the purpose of defining the Facial Characteristics of the Races and Principal Crosses in the British Isles, and obtaining illustrative Photographs with a view to their publication; that Mr. J. Park Harrison be the Secretary, and that the sum of 10*l.* be placed at their disposal for the purpose.

That Mr. Stainton, Sir John Lubbock, and Mr. E. C. Rye be reappointed a Committee for the purpose of continuing a Record of Zoological Literature; that Mr. Stainton be the Secretary, and that the sum of 100*l.* be placed at their disposal for the purpose.

That Mr. J. Cordeaux, Mr. J. A. Harvie Brown, Professor Newton, Mr. R. M. Barrington, Mr. A. G. More, Mr. J. Hardy, and Mr. P. Kermode be a Committee for the purpose of obtaining (with the consent of the Master and Elder Brethren of the Trinity House and of the Commissioners of Northern Lights) observations on the Migration of Birds at Lighthouses and Lightships, and of reporting upon the same at the

meeting of 1883; that Mr. J. Cordeaux be the Secretary, and that the sum of 20*l.* be placed at their disposal for the purpose.

That Professor Ray Lankester, Professor Newton, Professor Huxley, Mr. P. L. Sclater, Professor Allman, Dr. M. Foster, Mr. A. Sedgwick, and Mr. Percy Sladen be a Committee for the purpose of arranging for the Occupation of a Table at the Zoological Station at Naples; that Mr. Percy Sladen be the Secretary, and that the sum of 80*l.* be placed at their disposal for the purpose.

That Dr. Pye-Smith, Dr. M. Foster, Professor Huxley, Dr. Carpenter, Dr. Gwyn Jeffreys, Professor Lankester, Professor Allman, and Mr. Percy Sladen be a Committee for the purpose of aiding in the maintenance of the Scottish Zoological Station; that Mr. Percy Sladen be the Secretary, and that the sum of 25*l.* be placed at their disposal for the purpose.

That Dr. Pye-Smith, Professor de Chaumont, Dr. M. Foster, and Dr. Burdon Sanderson be reappointed a Committee for the purpose of investigating the Influence of Bodily Exercise on the Elimination of Nitrogen (the experiments to be conducted by Mr. North); that Dr. Burdon Sanderson be the Secretary, and that the sum of 30*l.* be placed at their disposal for the purpose.

That Sir Joseph Hooker, Dr. Günther, Mr. Howard Saunders, and Mr. P. L. Sclater be a Committee for the purpose of exploring Kilimandjaro and the adjoining mountains of Eastern Equatorial Africa; that Mr. P. L. Sclater be the Secretary, and that the sum of 500*l.* be placed at their disposal for the purpose.

That Mr. Raphael Meldola, General Pitt-Rivers, Mr. Worthington G. Smith, and Mr. William Cole be a Committee for the purpose of investigating the Ancient Earthwork in Epping Forest known as the Loughton Camp; that Mr. William Cole be the Secretary, and that the sum of 10*l.* be placed at their disposal for the purpose.

That Mr. Sclater, Mr. Howard Saunders, and Mr. W. Thiselton-Dyer be reappointed a Committee for the purpose of investigating the Natural History of Timor-laut; that Mr. W. Thiselton Dyer be the Secretary, and that the sum of 50*l.* be placed at their disposal for the purpose.

That Sir F. J. Bramwell, Mr. James Glaisher, Mr. C. W. Merrifield, Captain D. Galton, Professor W. C. Unwin, Mr. T. Hawksley, Major A. Cunningham, Mr. A. G. Greenhill, and Mr. A. T. Atchison be a Committee for the purpose of ascertaining by experiments and observations the relation between the pressure at different points of a surface on which water or air impinges and the velocity of the fluid, especially in the case of large actual structures, and thus to throw light upon some of the points on which information is much required, as stated in the report of the Committee on Wind Pressure; that Mr. Arthur T. Atchison be the Secretary, and that the sum of 25*l.* be placed at their disposal for the purpose.

That Sir Joseph Whitworth, Dr. Siemens, Sir F. J. Bramwell, Mr. A. Stroh, Mr. Beck, Mr. W. H. Preece, Mr. E. Crompton, Mr. E. Rigg, Mr. A. Le Neve Foster, Mr. Latimer Clark, Mr. H. Trueman Wood, Mr. Buckney, and Sir William Thomson be a Committee for the purpose of determining a Gauge for the manufacture of the various small Screws used in Telegraphic and Electrical Apparatus, in Clockwork, and for other analogous purposes; that Mr. H. Trueman Wood be the Secretary, and that the sum of 20*l.* be placed at their disposal for the purpose.

Not involving Grants of Money.

That Professor G. Carey Foster, Sir William Thomson, Professor Ayrton, Professor J. Perry, Professor W. G. Adams, Lord Rayleigh, Professor Jenkin, Dr. O. J. Lodge, Dr. John Hopkinson, Dr. A. Muirhead, Mr. W. H. Preece, Mr. Herbert Taylor, Professor Everett, and Professor Schuster be reappointed a Committee for the purpose of constructing and issuing practical Standards for use in Electrical Measurements, with the addition of the names of Dr. C. W. Siemens, Dr. J. A. Fleming, Professor G. F. Fitzgerald, Mr. R. T. Glazebrook, and Professor Chrystal; and that Dr. Muirhead be the Secretary.

That Professor Sylvester, Professor Cayley, and Professor Salmon be reappointed a Committee for the purpose of Calculating Tables of the Fundamental Invariants of Algebraic Forms; and that Professor Sylvester be the Secretary.

That Professor Schuster, Sir William Thomson, Professor H. E. Roscoe, Professor A. S. Herschel, Captain W. de W. Abney, Mr. R. H. Scott, and Dr. J. H. Gladstone be reappointed a Committee for the purpose of investigating the practicability of collecting and identifying Meteoric Dust, and of considering the question of undertaking regular observations in various localities; and that Professor Schuster be the Secretary.

That Mr. Spottiswoode, Professor Stokes, Professor Cayley, Professor Smith, Sir William Thomson, Professor Henrici, Lord Rayleigh, and Mr. J. W. L. Glaisher be reappointed a Committee on Mathematical Notation and Printing; and that Mr. J. W. L. Glaisher be the Secretary.

That Professor Cayley, Professor Stokes, Professor H. J. S. Smith, Sir William Thomson, Mr. James Glaisher, and Mr. J. W. L. Glaisher be reappointed a Committee on Mathematical Tables; and that Mr. J. W. L. Glaisher be the Secretary.

That Captain Abney, Professor W. G. Adams, Professor G. C. Foster, Lord Rayleigh, Mr. Preece, Professor Schuster, Professor Dewar, Professor Vernon Harcourt, and Professor Ayrton be reappointed a Committee for the purpose of fixing a Standard of White Light; and that Captain Abney be the Secretary.

That Captain Abney, Professor Stokes, and Professor Schuster be a Committee for the purpose of determining the best experimental methods that can be used in observing total Solar Eclipses; and that Professor Schuster be the Secretary.

That Professor Roscoe, Mr. Lockyer, Professor Dewar, Professor Liveing, Professor Schuster, Captain Abney, and Dr. Marshall Watts be reappointed a Committee for the purpose of preparing a new series of Wave-lengths Tables of the Spectra of the Elements; and that Dr. Marshall Watts be the Secretary.

That Professors Williamson, Frankland, Roscoe, Crum Brown, and Odling, and Messrs. J. Millar Thomson, V. H. Veley, and H. B. Dixon be a Committee for the purpose of drawing up a statement of the varieties of Chemical Names which have come into use, for indicating the causes which have led to their adoption, and for considering what can be done to bring about some convergence of the views on Chemical Nomenclature obtaining among English and foreign chemists; and that Mr. H. B. Dixon be the Secretary.

That Professors Dewar and A. W. Williamson, Dr. Marshall Watts,

y, Mr. Stoney, and Professors W. N. Hartley, McLeod, A. K. Huntington, Emerson Reynolds, Reinold, Liveing, h, Schuster, and W. Chandler Roberts be a Committee for)f reporting upon the present state of our knowledge of . Analysis; and that Professor W. Chandler Roberts be the Secretary.

That Professors F. A. Abel, A. K. Huntington, McLeod, Chandler Roberts, W. G. Adams, and Tilden and Mr. F. J. Bateman be a Committee for the purpose of collecting and arranging in a suitable form for reference the already published literature on the subject of Metallic Alloys; and that Professor A. K. Huntington be the Secretary.

That Professors J. Prestwich, V. Ball, J. W. Judd, and W. J. Sollas and Messrs. W. T. Blanford and W. Topley be a Committee for the purpose of inquiring into the possibility of securing the co-operation of foreign geologists in obtaining an International Geological Record; and that Professor W. J. Sollas be the Secretary.

That Professors J. Prestwich, W. Boyd Dawkins, T. McK. Hughes, and T. G. Bonney, the Rev. H. W. Crosskey, Dr. Deane, and Messrs. C. E. De Rance, H. G. Fordham, J. E. Lee, D. Mackintosh, W. Pengelly, J. Plant, and R. H. Tiddeman be a Committee for the purpose of recording the position, height above the sea, lithological characters, size, and origin of the Erratic Blocks of England, Wales, and Ireland, reporting other matters of interest connected with the same, and taking measures for their preservation; and that the Rev. H. W. Crosskey be the Secretary.

That Lieut.-Colonel H. H. Godwin-Austen, Dr. G. Hartlaub, Sir J. Hooker, Dr. Günther, Mr. Seebohm, and Mr. Sclater be reappointed a Committee for the purpose of investigating the Natural History of Socotra, and the adjacent Highlands of Arabia and Somali-land; and that Mr. Sclater be the Secretary.

That the Committee for promoting the Survey of Eastern Palestine, consisting of Mr. James Glaisher (Secretary), the Rev. Canon Tristram, and the Rev. F. Lawrence, be reappointed.

That Mr. James Heywood, Mr. William Shaen, Mr. Stephen Bourne, Mr. Robert Wilkinson, the Rev. W. Delany, Professor N. Story Maskelyne, Dr. Silvanus P. Thompson, Miss Lydia E. Becker, Sir John Lubbock, Professor A. W. Williamson, Mrs. Augusta Webster, the Rev. H. W. Crosskey, Professor Roscoe, Professor G. Carey Foster, and Dr. J. H. Gladstone (Secretary) be reappointed a Committee for the purpose of reporting on the workings of the Education Code and of other legislation affecting the Teaching of Science in Elementary Schools.

That Mr. F. Galton, Dr. Beddoe, Mr. Brabrook (Secretary and Reporter), Major-General Pitt-Rivers, Mr. Frank Fellows, Mr. J. P. Harrison, Mr. J. Heywood, Professor Leone Levi, Dr. F. A. Mahomed, Sir Rawson Rawson, Mr. J. E. Price, and Mr. C. Roberts be a Committee for the purpose of carrying out the recommendations of the Anthropometric Committee of last year and the more complete discussion of the collected facts.

That Sir Frederick Bramwell, Dr. A. W. Williamson, Professor Sir William Thomson, Mr. St. John Vincent Day, Dr. C. W. Siemens, Mr. C. W. Merrifield, Dr. Neilson Hancock, Mr. Abel, Captain Douglas Galton, Mr. Newmarch, Mr. E. H. Carbutt, Mr. Macrory, Mr. H. Trueman Wood, Mr. W. H. Barlow, and Mr. A. T. Atchison be reappointed a Committee for the purpose of watching and reporting to

the Council on Patent Legislation; and that Sir Frederick Bramwell be the Secretary.

That Sir William Thomson, Dr. C. W. Siemens, Mr. W. H. Barlow, Dr. A. W. Williamson, Mr. W. H. Preece, and Mr. J. M. Thomson be a Committee for the purpose of promoting arrangements for facilitating the use of Weights and Measures in accordance with the permissive clauses of the Weights and Measures Act, 1878; and that Mr. J. M. Thomson be the Secretary.

Communications ordered to be printed in extenso *in the Annual Report of the Association.*

Professor J. M. Crafts' paper, 'On the Boiling Points and Tension of Vapour of a number of Organic Substances determined with the Air-Thermometer.'

Mr. G. H. Darwin's paper, 'On a Misprint in the Tidal Report for 1872.'

Mr. W. Whitaker's 'List of Works on the Geology and Palæontology of Oxfordshire, Berkshire, and Buckinghamshire.'

Colonel Yule's paper, 'On the Oldest Records of the Sea Route to China from Western Asia.'

M. Pierre de Tchihatchef's paper, 'On the Deserts of Africa and Asia.'

Professor Leone Levi's paper, 'On the State of Crime in England, Scotland, and Ireland in 1880,' with accompanying diagrams and shaded map.

Sir W. G. Armstrong's paper, 'On the Treatment of Steel for the Construction of Ordnance, and other purposes.'

Mr. J. Clarke Hawkshaw's paper, 'On the Channel Tunnel,' with the necessary plans.

Mr. Baker's paper, 'On the Forth Bridge,' with the necessary cuts.

Resolutions referred to the Council for Consideration, and Action if desirable.

That the Council be empowered to take steps for amalgamating the Departments of Zoology and Botany and of Anatomy and Physiology for the ensuing year, should this seem desirable.

That the Council be empowered to appoint a Committee, as recommended in their report adopted by the General Committee on August 23, in order to draw up suggestions upon methods of more systematic observation and plans of operation for local societies, together with a more uniform mode of publication of the results of their work. It is recommended that this Committee should draw up a list of local societies which publish their proceedings.

That the Council be empowered to communicate with Foreign Scientific Associations with the view of promoting the organization of an International Scientific Congress.

That the Council be empowered to appoint a Committee, upon which the several sections of the Association be equally represented, for the purpose of co-operating with the Council in considering the best arrangements for securing a representative gathering of the Association at the meeting proposed to be held at Montreal.

Synopsis of Grants of Money appropriated to Scientific Purposes by the General Committee at the Southampton Meeting in August 1882. *The Names of the Members who would be entitled to call on the General Treasurer for the respective Grants are prefixed.*

Mathematics and Physics.

	£	s.	d.
Brown, Professor Crum.—Meteorological Observations on Ben Nevis	50	0	0
*Scott, Mr. R. H.—Synoptic Charts of the Indian Ocean	50	0	0
Darwin, Mr. G. H.—Harmonic Analysis of Tidal Observations	50	0	0

Chemistry.

Tilden, Professor W. A.—Investigating Isomeric Naphthalene Derivatives	15	0	0
*Odling, Professor.—Photographing the Ultra-Violet Spark-Spectra	20	0	0

Geology.

*Etheridge, Mr. R.—Earthquake Phenomena of Japan	50	0	0
*Williamson, Professor W. C.—Fossil Plants of Halifax	20	0	0
*Sorby, Dr. H. C.—British Fossil Polyzoa	10	0	0
Etheridge, Mr. R.—Fossil Phyllopoda of the Palæozoic Rocks	25	0	0
*Hawkshaw, Sir John.—Erosion of the Sea-coasts of England and Wales	10	0	0
*Hull, Professor E.—Circulation of Underground Waters	15	0	0
*Evans, Dr. J.—Geological Record	50	0	0
*Ball, Professor V.—Carboniferous Limestone Caves in the South of Ireland	20	0	0
Etheridge, Mr. R.—Llandovery Rocks of Central Wales	10	0	0
Carried forward	£395	0	0

* Reappointed.

	£	s.	d.
Brought forward	395	0	0

Biology.

*Pitt-Rivers, General.—Photographs of the Races and principal Crosses in the British Isles	10	0	0
*Stainton, Mr.—Record of Zoological Literature	100	0	0
*Cordeaux, Mr. J.—Migration of Birds	20	0	0
*Lankester, Professor Ray.—Table at the Zoological Station at Naples	80	0	0
*Pye-Smith, Dr.—Scottish Zoological Station	25	0	0
*Pye-Smith, Dr.—Influence of Bodily Exercise on the Elimination of Nitrogen	30	0	0
Hooker, Sir J.—Exploring Kilimandjaro and the adjoining Mountains of Eastern Equatorial Africa	500	0	0
*Meldola, Mr. R.—Investigation of Loughton Camp	10	0	0
*Sclater, Mr. P. L.—Natural History of Timor-laut	50	0	0

Mechanics.

Bramwell, Sir F. J.—Relation between the pressure at different points of a structure on which water and air impinge	25	0	0
*Whitworth, Sir Joseph.—Screw Gauges	20	0	0
	£1265	0	0

* Reappointed.

The Annual Meeting in 1883.

The Meeting will commence on Wednesday, September 19, at Southport, instead of Oxford (see Council Report, p. lix).

Place of Meeting in 1884.

The Annual Meeting of the Association in 1884 will be held at Montreal.

General Statement of Sums which have been paid on Account of Grants for Scientific Purposes.

	£	s.	d.
1834.			
Tide Discussions	20	0	0
1835.			
Tide Discussions	62	0	0
British Fossil Ichthyology	105	0	0
	£167	0	0
1836.			
Tide Discussions	163	0	0
British Fossil Ichthyology	105	0	0
Thermometric Observations, &c.	50	0	0
Experiments on long-continued Heat	17	1	0
Rain-Gauges	9	13	0
Refraction Experiments	15	0	0
Lunar Nutation	60	0	0
Thermometers	15	6	0
	£435	0	0
1837.			
Tide Discussions	284	1	0
Chemical Constants	24	13	6
Lunar Nutation	70	0	0
Observations on Waves	100	12	0
Tides at Bristol	150	0	0
Meteorology and Subterranean Temperature	93	3	0
Vitrification Experiments	150	0	0
Heart Experiments	8	4	6
Barometric Observations	30	0	0
Barometers	11	18	6
	£922	12	6
1838.			
Tide Discussions	29	0	0
British Fossil Fishes	100	0	0
Meteorological Observations and Anemometer (construction)	100	0	0
Cast Iron (Strength of)	60	0	0
Animal and Vegetable Substances (Preservation of)	19	1	10
Railway Constants	41	12	10
Bristol Tides	50	0	0
Growth of Plants	75	0	0
Mud in Rivers	3	6	6
Education Committee	50	0	0
Heart Experiments	5	3	0
Land and Sea Level	267	8	7
Steam-vessels	100	0	0
Meteorological Committee	31	9	5
	£932	2	2
1839.			
Fossil Ichthyology	110	0	0
Meteorological Observations at Plymouth, &c.	63	10	0
Mechanism of Waves	144	2	0
Bristol Tides	35	18	6
Meteorology and Subterranean Temperature	21	11	0
Vitrification Experiments	9	4	7
Cast-Iron Experiments	100	0	0
Railway Constants	28	7	2
Land and Sea Level	274	1	4
Steam-vessels' Engines	100	0	0
Stars in Histoire Céleste	171	18	6
Stars in Lacaille	11	0	0
Stars in R.A.S. Catalogue	166	16	6
Animal Secretions	10	10	0
Steam Engines in Cornwall	50	0	0
Atmospheric Air	16	1	0
Cast and Wrought Iron	40	0	0
Heat on Organic Bodies	3	0	0
Gases on Solar Spectrum	22	0	0
Hourly Meteorological Observations, Inverness and Kingussie	49	7	8
Fossil Reptiles	118	2	9
Mining Statistics	50	0	0
	£1595	11	0
1840.			
Bristol Tides	100	0	0
Subterranean Temperature	13	13	6
Heart Experiments	18	19	0
Lungs Experiments	8	13	0
Tide Discussions	50	0	0
Land and Sea Level	6	11	1
Stars (Histoire Céleste)	242	10	0
Stars (Lacaille)	4	15	0
Stars (Catalogue)	264	0	0
Atmospheric Air	15	15	0
Water on Iron	10	0	0
Heat on Organic Bodies	7	0	0
Meteorological Observations	52	17	6
Foreign Scientific Memoirs	112	1	6
Working Population	100	0	0
School Statistics	50	0	0
Forms of Vessels	184	7	0
Chemical and Electrical Phenomena	40	0	0
Meteorological Observations at Plymouth	80	0	0
Magnetical Observations	185	13	9
	£1546	16	4
1841.			
Observations on Waves	30	0	0
Meteorology and Subterranean Temperature	8	8	0
Actinometers	10	0	0
Earthquake Shocks	17	7	0
Acrid Poisons	6	0	0
Veins and Absorbents	3	0	0
Mud in Rivers	5	0	0

	£	s.	d.
Marine Zoology.................	15	12	8
Skeleton Maps	20	0	0
Mountain Barometers	6	18	6
Stars (Histoire Céleste)	185	0	0
Stars (Lacaille)	79	5	0
Stars (Nomenclature of)......	17	19	6
Stars (Catalogue of)...........	40	0	0
Water on Iron	50	0	0
Meteorological Observations at Inverness	20	0	0
Meteorological Observations (reduction of)	25	0	0
Fossil Reptiles	50	0	0
Foreign Memoirs	62	0	6
Railway Sections	38	1	0
Forms of Vessels	193	12	0
Meteorological Observations at Plymouth	55	0	0
Magnetical Observations......	61	18	8
Fishes of the Old Red Sandstone	100	0	0
Tides at Leith	50	0	0
Anemometer at Edinburgh...	69	1	10
Tabulating Observations......	9	6	3
Races of Men....................	5	0	0
Radiate Animals	2	0	0
	£1235	10	11

1842.

	£	s.	d.
Dynamometric Instruments...	113	11	2
Anoplura Britanniæ	52	12	0
Tides at Bristol.................	59	8	0
Gases on Light	30	14	7
Chronometers	26	17	6
Marine Zoology.................	1	5	0
British Fossil Mammalia......	100	0	0
Statistics of Education	20	0	0
Marine Steam-vessels' Engines	28	0	0
Stars (Histoire Céleste)	59	0	0
Stars (Brit. Assoc. Cat. of)...	110	0	0
Railway Sections	161	10	0
British Belemnites	50	0	0
Fossil Reptiles (publication of Report)	210	0	0
Forms of Vessels	180	0	0
Galvanic Experiments on Rocks	5	8	6
Meteorological Experiments at Plymouth	68	0	0
Constant Indicator and Dynamometric Instruments	90	0	0
Force of Wind	10	0	0
Light on Growth of Seeds ...	8	0	0
Vital Statistics	50	0	0
Vegetative Power of Seeds...	8	1	11
Questions on Human Race ...	7	9	0
	£1449	17	8

1843.

	£	s.	d.
Revision of the Nomenclature of Stars	2	0	0
Reduction of Stars, British Association Catalogue	25	0	0
Anomalous Tides, Frith of Forth	120	0	0
Hourly Meteorological Observations at Kingussie and Inverness	77	12	8
Meteorological Observations at Plymouth	55	0	0
Whewell's Meteorological Anemometer at Plymouth .	10	0	0
Meteorological Observations, Osler's Anemometer at Plymouth	20	0	0
Reduction of Meteorological Observations	30	0	0
Meteorological Instruments and Gratuities	39	6	0
Construction of Anemometer at Inverness	56	12	2
Magnetic Co-operation.........	10	8	10
Meteorological Recorder for Kew Observatory	50	0	0
Action of Gases on Light......	18	16	1
Establishment at Kew Observatory, Wages, Repairs, Furniture, and Sundries ...	133	4	7
Experiments by Captive Balloons	81	8	0
Oxidation of the Rails of Railways............................	20	0	0
Publication of Report on Fossil Reptiles....................	40	0	0
Coloured Drawings of Railway Sections	147	18	3
Registration of Earthquake Shocks	30	0	0
Report on Zoological Nomenclature..........................	10	0	0
Uncovering Lower Red Sandstone near Manchester......	4	4	6
Vegetative Power of Seeds...	5	3	8
Marine Testacea (Habits of).	10	0	0
Marine Zoology..................	10	0	0
Marine Zoology..................	2	14	11
Preparation of Report on British Fossil Mammalia	100	0	0
Physiological Operations of Medicinal Agents	20	0	0
Vital Statistics	36	5	8
Additional Experiments on the Forms of Vessels	70	0	0
Additional Experiments on the Forms of Vessels	100	0	0
Reduction of Experiments on the Forms of Vessels	100	0	0
Morin's Instrument and Constant Indicator	69	14	10
Experiments on the Strength of Materials	60	0	0
	£1565	10	2

1844.

	£	s.	d.
Meteorological Observations at Kingussie and Inverness	12	0	0
Completing Observations at Plymouth	35	0	0
Magnetic and Meteorological Co-operation	25	8	4
Publication of the British Association Catalogue of Stars	35	0	0
Observations on Tides on the East Coast of Scotland	100	0	0
Revision of the Nomenclature of Stars 1842	2	9	6
Maintaining the Establishment in Kew Observatory	117	17	3
Instruments for Kew Observatory	56	7	3
Influence of Light on Plants	10	0	0
Subterraneous Temperature in Ireland	5	0	0
Coloured Drawings of Railway Sections	15	17	6
Investigation of Fossil Fishes of the Lower Tertiary Strata	100	0	0
Registering the Shocks of Earthquakes 1842	23	11	10
Structure of Fossil Shells	20	0	0
Radiata and Mollusca of the Ægean and Red Seas 1842	100	0	0
Geographical Distributions of Marine Zoology 1842	0	10	0
Marine Zoology of Devon and Cornwall	10	0	0
Marine Zoology of Corfu	10	0	0
Experiments on the Vitality of Seeds	9	0	0
Experiments on the Vitality of Seeds 1842	8	7	3
Exotic Anoplura	15	0	0
Strength of Materials	100	0	0
Completing Experiments on the Forms of Ships	100	0	0
Inquiries into Asphyxia	10	0	0
Investigations on the Internal Constitution of Metals	50	0	0
Constant Indicator and Morin's Instrument 1842	10	0	0
	£981	12	8

1845.

	£	s.	d.
Publications of the British Association Catalogue of Stars	351	14	6
Meteorological Observations at Inverness	30	18	11
Magnetic and Meteorological Co-operation	16	16	8
Meteorological Instruments at Edinburgh	18	11	9
Reduction of Anemometrical Observations at Plymouth	25	0	0
Electrical Experiments at Kew Observatory	43	17	8
Maintaining the Establishment in Kew Observatory	149	15	0
For Kreil's Barometrograph	25	0	0
Gases from Iron Furnaces	50	0	0
The Actinograph	15	0	0
Microscopic Structure of Shells	20	0	0
Exotic Anoplura 1843	10	0	0
Vitality of Seeds 1843	2	0	7
Vitality of Seeds 1844	7	0	0
Marine Zoology of Cornwall	10	0	0
Physiological Action of Medicines	20	0	0
Statistics of Sickness and Mortality in York	20	0	0
Earthquake Shocks 1843	15	14	8
	£831	9	9

1846.

	£	s.	d.
British Association Catalogue of Stars 1844	211	15	0
Fossil Fishes of the London Clay	100	0	0
Computation of the Gaussian Constants for 1829	50	0	0
Maintaining the Establishment at Kew Observatory	146	16	7
Strength of Materials	60	0	0
Researches in Asphyxia	6	16	2
Examination of Fossil Shells	10	0	0
Vitality of Seeds 1844	2	15	10
Vitality of Seeds 1845	7	12	3
Marine Zoology of Cornwall	10	0	0
Marine Zoology of Britain	10	0	0
Exotic Anoplura 1844	25	0	0
Expenses attending Anemometers	11	7	6
Anemometers' Repairs	2	3	6
Atmospheric Waves	3	3	3
Captive Balloons 1844	8	19	8
Varieties of the Human Race 1844	7	6	3
Statistics of Sickness and Mortality in York	12	0	0
	£685	16	0

1847.

	£	s.	d.
Computation of the Gaussian Constants for 1829	50	0	0
Habits of Marine Animals	10	0	0
Physiological Action of Medicines	20	0	0
Marine Zoology of Cornwall	10	0	0
Atmospheric Waves	6	9	3
Vitality of Seeds	4	7	7
Maintaining the Establishment at Kew Observatory	107	8	6
	£208	5	4

	£	s.	d.
1848.			
Maintaining the Establishment at Kew Observatory	171	15	11
Atmospheric Waves	3	10	9
Vitality of Seeds	9	15	0
Completion of Catalogue of Stars	70	0	0
On Colouring Matters	5	0	0
On Growth of Plants	15	0	0
	£275	1	8
1849.			
Electrical Observations at Kew Observatory	50	0	0
Maintaining Establishment at ditto	76	2	5
Vitality of Seeds	5	8	1
On Growth of Plants	5	0	0
Registration of Periodical Phenomena	10	0	0
Bill on Account of Anemometrical Observations	13	9	0
	£159	19	6
1850.			
Maintaining the Establishment at Kew Observatory	255	18	0
Transit of Earthquake Waves	50	0	0
Periodical Phenomena	15	0	0
Meteorological Instruments, Azores	25	0	0
	£345	18	0
1851.			
Maintaining the Establishment at Kew Observatory (includes part of grant in 1849)	309	2	2
Theory of Heat	20	1	1
Periodical Phenomena of Animals and Plants	5	0	0
Vitality of Seeds	5	6	4
Influence of Solar Radiation	30	0	0
Ethnological Inquiries	12	0	0
Researches on Annelida	10	0	0
	£391	9	7
1852.			
Maintaining the Establishment at Kew Observatory (including balance of grant for 1850)	233	17	8
Experiments on the Conduction of Heat	5	2	9
Influence of Solar Radiations	20	0	0
Geological Map of Ireland	15	0	0
Researches on the British Annelida	10	0	0
Vitality of Seeds	10	6	2
Strength of Boiler Plates	10	0	0
	£304	6	7
1853.			
Maintaining the Establishment at Kew Observatory	165	0	0
Experiments on the Influence of Solar Radiation	15	0	0
Researches on the British Annelida	10	0	0
Dredging on the East Coast of Scotland	10	0	0
Ethnological Queries	5	0	0
	£205	0	0
1854.			
Maintaining the Establishment at Kew Observatory (including balance of former grant)	330	15	4
Investigations on Flax	11	0	0
Effects of Temperature on Wrought Iron	10	0	0
Registration of Periodical Phenomena	10	0	0
British Annelida	10	0	0
Vitality of Seeds	5	2	3
Conduction of Heat	4	2	0
	£380	19	7
1855.			
Maintaining the Establishment at Kew Observatory	425	0	0
Earthquake Movements	10	0	0
Physical Aspect of the Moon	11	8	5
Vitality of Seeds	10	7	11
Map of the World	15	0	0
Ethnological Queries	5	0	0
Dredging near Belfast	4	0	0
	£480	16	4
1856.			
Maintaining the Establishment at Kew Observatory:— 1854.........£ 75 0 0; 1855.........£500 0 0	575	0	0
Strickland's Ornithological Synonyms	100	0	0
Dredging and Dredging Forms	9	13	9
Chemical Action of Light	20	0	0
Strength of Iron Plates	10	0	0
Registration of Periodical Phenomena	10	0	0
Propagation of Salmon	10	0	0
	£734	13	9
1857.			
Maintaining the Establishment at Kew Observatory	350	0	0
Earthquake Wave Experiments	40	0	0
Dredging near Belfast	10	0	0
Dredging on the West Coast of Scotland	10	0	0

	£	s.	d.
Investigations into the Mollusca of California	10	0	0
Experiments on Flax	5	0	0
Natural History of Madagascar	20	0	0
Researches on British Annelida	25	0	0
Report on Natural Products imported into Liverpool	10	0	0
Artificial Propagation of Salmon	10	0	0
Temperature of Mines	7	8	0
Thermometers for Subterranean Observations	5	7	4
Life-boats	5	0	0
	£507	15	4

1858.

	£	s.	d.
Maintaining the Establishment at Kew Observatory	500	0	0
Earthquake Wave Experiments	25	0	0
Dredging on the West Coast of Scotland	10	0	0
Dredging near Dublin	5	0	0
Vitality of Seeds	5	5	0
Dredging near Belfast	18	13	2
Report on the British Annelida	25	0	0
Experiments on the production of Heat by Motion in Fluids	20	0	0
Report on the Natural Products imported into Scotland	10	0	0
	£618	18	2

1859.

	£	s.	d.
Maintaining the Establishment at Kew Observatory	500	0	0
Dredging near Dublin	15	0	0
Osteology of Birds	50	0	0
Irish Tunicata	5	0	0
Manure Experiments	20	0	0
British Medusidæ	5	0	0
Dredging Committee	5	0	0
Steam-vessels' Performance	5	0	0
Marine Fauna of South and West of Ireland	10	0	0
Photographic Chemistry	10	0	0
Lanarkshire Fossils	20	0	1
Balloon Ascents	39	11	0
	£684	11	1

1860.

	£	s.	d.
Maintaining the Establishment of Kew Observatory	500	0	0
Dredging near Belfast	16	6	0
Dredging in Dublin Bay	15	0	0
Inquiry into the Performance of Steam-vessels	124	0	0
Explorations in the Yellow Sandstone of Dura Den	20	0	0
Chemico-mechanical Analysis of Rocks and Minerals	25	0	0
Researches on the Growth of Plants	10	0	0
Researches on the Solubility of Salts	30	0	0
Researches on the Constituents of Manures	25	0	0
Balance of Captive Balloon Accounts	1	13	6
	£766	19	6

1861.

	£	s.	d.
Maintaining the Establishment of Kew Observatory	500	0	0
Earthquake Experiments	25	0	0
Dredging North and East Coasts of Scotland	23	0	0
Dredging Committee:— 1860......£50 0 0; 1861......£22 0 0	72	0	0
Excavations at Dura Den	20	0	0
Solubility of Salts	20	0	0
Steam-vessel Performance	150	0	0
Fossils of Lesmahago	15	0	0
Explorations at Uriconium	20	0	0
Chemical Alloys	20	0	0
Classified Index to the Transactions	100	0	0
Dredging in the Mersey and Dee	5	0	0
Dip Circle	30	0	0
Photoheliographic Observations	50	0	0
Prison Diet	20	0	0
Gauging of Water	10	0	0
Alpine Ascents	6	5	10
Constituents of Manures	25	0	0
	£1111	5	10

1862.

	£	s.	d.
Maintaining the Establishment of Kew Observatory	500	0	0
Patent Laws	21	6	0
Mollusca of N.-W. of America	10	0	0
Natural History by Mercantile Marine	5	0	0
Tidal Observations	25	0	0
Photoheliometer at Kew	40	0	0
Photographic Pictures of the Sun	150	0	0
Rocks of Donegal	25	0	0
Dredging Durham and Northumberland	25	0	0
Connexion of Storms	20	0	0
Dredging North-east Coast of Scotland	6	9	6
Ravages of Teredo	3	11	0
Standards of Electrical Resistance	50	0	0
Railway Accidents	10	0	0
Balloon Committee	200	0	0
Dredging Dublin Bay	10	0	

	£	s.	d.
Dredging the Mersey	5	0	0
Prison Diet	20	0	0
Gauging of Water	12	10	0
Steamships' Performance......	150	0	0
Thermo-Electric Currents ...	5	0	0
	£1293	16	6

1863.

	£	s.	d.
Maintaining the Establishment of Kew Observatory..	600	0	0
Balloon Committee deficiency	70	0	0
Balloon Ascents (other expenses)	25	0	0
Entozoa	25	0	0
Coal Fossils	20	0	0
Herrings	20	0	0
Granites of Donegal...........	5	0	0
Prison Diet	20	0	0
Vertical Atmospheric Movements	13	0	0
Dredging Shetland	50	0	0
Dredging North-east coast of Scotland	25	0	0
Dredging Northumberland and Durham	17	3	10
Dredging Committee superintendence	10	0	0
Steamship Performance	100	0	0
Balloon Committee	200	0	0
Carbon under pressure	10	0	0
Volcanic Temperature	100	0	0
Bromide of Ammonium	8	0	0
Electrical Standards...........	100	0	0
—— Construction and Distribution	40	0	0
Luminous Meteors	17	0	0
Kew Additional Buildings for Photoheliograph	100	0	0
Thermo-Electricity	15	0	0
Analysis of Rocks	8	0	0
Hydroida..........................	10	0	0
	£1608	3	10

1864.

	£	s.	d.
Maintaining the Establishment of Kew Observatory..	600	0	0
Coal Fossils	20	0	0
Vertical Atmospheric Movements	20	0	0
Dredging Shetland	75	0	0
Dredging Northumberland ...	25	0	0
Balloon Committee	200	0	0
Carbon under pressure	10	0	0
Standards of Electric Resistance	100	0	0
Analysis of Rocks	10	0	0
Hydroida	10	0	0
Askham's Gift	50	0	0
Nitrite of Amyle	10	0	0
Nomenclature Committee ...	5	0	0
Rain-Gauges	19	15	8
Cast-Iron Investigation	20	0	0
Tidal Observations in the Humber	50	0	0
Spectral Rays....................	45	0	0
Luminous Meteors	20	0	0
	£1289	15	8

1865.

	£	s.	d.
Maintaining the Establishment of Kew Observatory..	600	0	0
Balloon Committee	100	0	0
Hydroida..........................	13	0	0
Rain-Gauges	30	0	0
Tidal Observations in the Humber	6	8	0
Hexylic Compounds	20	0	0
Amyl Compounds	20	0	0
Irish Flora	25	0	0
American Mollusca	3	9	0
Organic Acids	20	0	0
Lingula Flags Excavation ...	10	0	0
Eurypterus	50	0	0
Electrical Standards...........	100	0	0
Malta Caves Researches	30	0	0
Oyster Breeding	25	0	0
Gibraltar Caves Researches...	150	0	0
Kent's Hole Excavations......	100	0	0
Moon's Surface Observations	35	0	0
Marine Fauna	25	0	0
Dredging Aberdeenshire	25	0	0
Dredging Channel Islands ...	50	0	0
Zoological Nomenclature......	5	0	0
Resistance of Floating Bodies in Water	100	0	0
Bath Waters Analysis	8	10	10
Luminous Meteors	40	0	0
	£1591	7	10

1866.

	£	s.	d.
Maintaining the Establishment of Kew Observatory..	600	0	0
Lunar Committee	64	13	4
Balloon Committee	50	0	0
Metrical Committee...........	50	0	0
British Rainfall.................	50	0	0
Kilkenny Coal Fields	16	0	0
Alum Bay Fossil Leaf-Bed ...	15	0	0
Luminous Meteors	50	0	0
Lingula Flags Excavation ...	20	0	0
Chemical Constitution of Cast Iron	50	0	0
Amyl Compounds	25	0	0
Electrical Standards...........	100	0	0
Malta Caves Exploration	30	0	0
Kent's Hole Exploration	200	0	0
Marine Fauna, &c., Devon and Cornwall	25	0	0
Dredging Aberdeenshire Coast	25	0	0
Dredging Hebrides Coast ...	50	0	0
Dredging the Mersey	5	0	0
Resistance of Floating Bodies in Water.......................	50	0	0
Polycyanides of Organic Radicals	20	0	0

	£	s.	d.
Rigor Mortis	10	0	0
Irish Annelida	15	0	0
Catalogue of Crania	50	0	0
Didine Birds of Mascarene Islands	50	0	0
Typical Crania Researches	30	0	0
Palestine Exploration Fund	100	0	0
	£1750	13	4

1867.

	£	s.	d.
Maintaining the Establishment of Kew Observatory	600	0	0
Meteorological Instruments, Palestine	50	0	0
Lunar Committee	120	0	0
Metrical Committee	30	0	0
Kent's Hole Explorations	100	0	0
Palestine Explorations	50	0	0
Insect Fauna, Palestine	30	0	0
British Rainfall	50	0	0
Kilkenny Coal Fields	25	0	0
Alum Bay Fossil Leaf-Bed	25	0	0
Luminous Meteors	50	0	0
Bournemouth, &c., Leaf-Beds	30	0	0
Dredging Shetland	75	0	0
Steamship Reports Condensation	100	0	0
Electrical Standards	100	0	0
Ethyl and Methyl series	25	0	0
Fossil Crustacea	25	0	0
Sound under Water	24	4	0
North Greenland Fauna	75	0	0
Do. Plant Beds	100	0	0
Iron and Steel Manufacture	25	0	0
Patent Laws	30	0	0
	£1739	4	0

1868.

	£	s.	d.
Maintaining the Establishment of Kew Observatory	600	0	0
Lunar Committee	120	0	0
Metrical Committee	50	0	0
Zoological Record	100	0	0
Kent's Hole Explorations	150	0	0
Steamship Performances	100	0	0
British Rainfall	50	0	0
Luminous Meteors	50	0	0
Organic Acids	60	0	0
Fossil Crustacea	25	0	0
Methyl Series	25	0	0
Mercury and Bile	25	0	0
Organic Remains in Limestone Rocks	25	0	0
Scottish Earthquakes	20	0	0
Fauna, Devon and Cornwall	30	0	0
British Fossil Corals	50	0	0
Bagshot Leaf-Beds	50	0	0
Greenland Explorations	100	0	0
Fossil Flora	25	0	0
Tidal Observations	100	0	0
Underground Temperature	50	0	0
Spectroscopic Investigations of Animal Substances	5	0	0
Secondary Reptiles, &c.	30	0	0
British Marine Invertebrate Fauna	100	0	0
	£1940	0	0

1869.

	£	s.	d.
Maintaining the Establishment of Kew Observatory	600	0	0
Lunar Committee	50	0	0
Metrical Committee	25	0	0
Zoological Record	100	0	0
Committee on Gases in Deep-well Water	25	0	0
British Rainfall	50	0	0
Thermal Conductivity of Iron, &c.	30	0	0
Kent's Hole Explorations	150	0	0
Steamship Performances	30	0	0
Chemical Constitution of Cast Iron	80	0	0
Iron and Steel Manufacture	100	0	0
Methyl Series	30	0	0
Organic Remains in Limestone Rocks	10	0	0
Earthquakes in Scotland	10	0	0
British Fossil Corals	50	0	0
Bagshot Leaf-Beds	30	0	0
Fossil Flora	25	0	0
Tidal Observations	100	0	0
Underground Temperature	30	0	0
Spectroscopic Investigations of Animal Substances	5	0	0
Organic Acids	12	0	0
Kiltorcan Fossils	20	0	0
Chemical Constitution and Physiological Action Relations	15	0	0
Mountain Limestone Fossils	25	0	0
Utilization of Sewage	10	0	0
Products of Digestion	10	0	0
	£1622	0	0

1870.

	£	s.	d.
Maintaining the Establishment of Kew Observatory	600	0	0
Metrical Committee	25	0	0
Zoological Record	100	0	0
Committee on Marine Fauna	20	0	0
Ears in Fishes	10	0	0
Chemical Nature of Cast Iron	80	0	0
Luminous Meteors	30	0	0
Heat in the Blood	15	0	0
British Rainfall	100	0	0
Thermal Conductivity of Iron, &c.	20	0	0
British Fossil Corals	50	0	0
Kent's Hole Explorations	150	0	0
Scottish Earthquakes	4	0	0
Bagshot Leaf-Beds	15	0	0
Fossil Flora	25	0	0
Tidal Observations	100	0	0
Underground Temperature	50	0	0
Kiltorcon Quatries Fossils	20	0	0

	£	s.	d.
Mountain Limestone Fossils	25	0	0
Utilization of Sewage	50	0	0
Organic Chemical Compounds	30	0	0
Onny River Sediment	3	0	0
Mechanical Equivalent of Heat..............................	50	0	0
	£1572	0	0

1871.

	£	s.	d.
Maintaining the Establishment of Kew Observatory	600	0	0
Monthly Reports of Progress in Chemistry	100	0	0
Metrical Committee...........	25	0	0
Zoological Record..............	100	0	0
Thermal Equivalents of the Oxides of Chlorine	10	0	0
Tidal Observations	100	0	0
Fossil Flora	25	0	0
Luminous Meteors	30	0	0
British Fossil Corals	25	0	0
Heat in the Blood.........	7	2	6
British Rainfall.................	50	0	0
Kent's Hole Explorations ...	150	0	0
Fossil Crustacea	25	0	0
Methyl Compounds	25	0	0
Lunar Objects	20	0	0
Fossil Coral Sections, for Photographing	20	0	0
Bagshot Leaf-Beds	20	0	0
Moab Explorations	100	0	0
Gaussian Constants	40	0	0
	£1472	2	6

1872.

	£	s.	d.
Maintaining the Establishment of Kew Observatory	300	0	0
Metrical Committee...........	75	0	0
Zoological Record..............	100	0	0
Tidal Committee	200	0	0
Carboniferous Corals	25	0	0
Organic Chemical Compounds	25	0	0
Exploration of Moab...........	100	0	0
Terato-Embryological Inquiries	10	0	0
Kent's Cavern Exploration...	100	0	0
Luminous Meteors	20	0	0
Heat in the Blood..............	15	0	0
Fossil Crustacea	25	0	0
Fossil Elephants of Malta ...	25	0	0
Lunar Objects	20	0	0
Inverse Wave-Lengths.........	20	0	0
British Rainfall.................	100	0	0
Poisonous Substances Antagonism...............................	10	0	0
Essential Oils, Chemical Constitution, &c.	40	0	0
Mathematical Tables	50	0	0
Thermal Conductivity of Metals	25	0	0
	£1285	0	0

1873.

	£	s.	d.
Zoological Record..............	100	0	0
Chemistry Record..............	200	0	0
Tidal Committee	400	0	0
Sewage Committee	100	0	0
Kent's Cavern Exploration ...	150	0	0
Carboniferous Corals	25	0	0
Fossil Elephants	25	0	0
Wave-Lengths	150	0	0
British Rainfall.................	100	0	0
Essential Oils.....................	30	0	0
Mathematical Tables	100	0	0
Gaussian Constants	10	0	0
Sub-Wealden Explorations...	25	0	0
Underground Temperature ...	150	0	0
Settle Cave Exploration	50	0	0
Fossil Flora, Ireland...........	20	0	0
Timber Denudation and Rainfall	20	0	0
Luminous Meteors..............	30	0	0
	£1685	0	0

1874.

	£	s.	d.
Zoological Record..............	100	0	0
Chemistry Record..............	100	0	0
Mathematical Tables	100	0	0
Elliptic Functions..............	100	0	0
Lightning Conductors	10	0	0
Thermal Conductivity of Rocks	10	0	0
Anthropological Instructions, &c.	50	0	0
Kent's Cavern Exploration ...	150	0	0
Luminous Meteors	30	0	0
Intestinal Secretions	15	0	0
British Rainfall.................	100	0	0
Essential Oils.....................	10	0	0
Sub-Wealden Explorations ...	25	0	0
Settle Cave Exploration	50	0	0
Mauritius Meteorological Research	100	0	0
Magnetization of Iron	20	0	0
Marine Organisms..............	30	0	0
Fossils, North-West of Scotland	2	10	0
Physiological Action of Light	20	0	0
Trades Unions	25	0	0
Mountain Limestone-Corals	25	0	0
Erratic Blocks	10	0	0
Dredging, Durham and Yorkshire Coasts	28	5	0
High Temperature of Bodies	30	0	0
Siemens's Pyrometer	3	6	0
Labyrinthodonts of Coal-Measures.........................	7	15	0
	£1151	16	0

1875.

	£	s.	d.
Eliptic Functions	100	0	0
Magnetization of Iron	20	0	0
British Rainfall.................	120	0	0
Luminous Meteors	30	0	0
Chemistry Record..............	100	0	0

	£	s.	d.
Specific Volume of Liquids...	25	0	0
Estimation of Potash and Phosphoric Acid	10	0	0
Isometric Cresols	20	0	0
Sub-Wealden Explorations...	100	0	0
Kent's Cavern Exploration...	100	0	0
Settle Cave Exploration	50	0	0
Earthquakes in Scotland	15	0	0
Underground Waters	10	0	0
Development of Myxinoid Fishes	20	0	0
Zoological Record	100	0	0
Instructions for Travellers ...	20	0	0
Intestinal Secretions	20	0	0
Palestine Exploration	100	0	0
	£960	0	0

1876.

	£	s.	d.
Printing Mathematical Tables	159	4	2
British Rainfall	100	0	0
Ohm's Law	9	15	0
Tide Calculating Machine ...	200	0	0
Specific Volume of Liquids...	25	0	0
Isomeric Cresols	10	0	0
Action of Ethyl Bromobutyrate or Ethyl Sodaceto-acetate	5	0	0
Estimation of Potash and Phosphoric Acid	13	0	0
Exploration of Victoria Cave, Settle	100	0	0
Geological Record	100	0	0
Kent's Cavern Exploration...	100	0	0
Thermal Conductivities of Rocks	10	0	0
Underground Waters	10	0	0
Earthquakes in Scotland	1	10	0
Zoological Record	100	0	0
Close Time	5	0	0
Physiological Action of Sound	25	0	0
Zoological Station	75	0	0
Intestinal Secretions	15	0	0
Physical Characters of Inhabitants of British Isles	13	15	0
Measuring Speed of Ships ...	10	0	0
Effect of Propeller on turning of Steam Vessels	5	0	0
	£1092	4	2

1877.

	£	s.	d.
Liquid Carbonic Acids in Minerals	20	0	0
Elliptic Functions	250	0	0
Thermal Conductivity of Rocks	9	11	7
Zoological Record	100	0	0
Kent's Cavern	100	0	0
Zoological Station at Naples	75	0	0
Luminous Meteors	30	0	0
Elasticity of Wires	100	0	0
Dipterocarpæ, Report on	20	0	0
Mechanical Equivalent of Heat	35	0	0
Double Compounds of Cobalt and Nickel	8	0	0
Underground Temperatures	50	0	0
Settle Cave Exploration	100	0	0
Underground Waters in New Red Sandstone	10	0	0
Action of Ethyl Bromobutyrate on Ethyl Sodaceto-acetate	10	0	0
British Earthworks	25	0	0
Atmospheric Elasticity in India	15	0	0
Development of Light from Coal-gas	20	0	0
Estimation of Potash and Phosphoric Acid	1	18	0
Geological Record	100	0	0
Anthropometric Committee	34	0	0
Physiological Action of Phosphoric Acid, &c.	15	0	0
	£1128	9	7

1878.

	£	s.	d.
Exploration of Settle Caves	100	0	0
Geological Record	100	0	0
Investigation of Pulse Phenomena by means of Syphon Recorder	10	0	0
Zoological Station at Naples	75	0	0
Investigation of Underground Waters	15	0	0
Transmission of Electrical Impulses through Nerve Structure	30	0	0
Calculation of Factor Table of Fourth Million	100	0	0
Anthropometric Committee...	66	0	0
Chemical Composition and Structure of less known Alkaloids	25	0	0
Exploration of Kent's Cavern	50	0	0
Zoological Record	100	0	0
Fermanagh Caves Exploration	15	0	0
Thermal Conductivity of Rocks	4	16	6
Luminous Meteors	10	0	0
Ancient Earthworks	25	0	0
	£725	16	6

1879.

	£	s.	d.
Table at the Zoological Station, Naples	75	0	0
Miocene Flora of the Basalt of the North of Ireland ...	20	0	0
Illustrations for a Monograph on the Mammoth	17	0	0
Record of Zoological Literature	100	0	0
Composition and Structure of less-known Alkaloids	25	0	0

	£	s.	d.
Exploration of Caves in Borneo	50	0	0
Kent's Cavern Exploration ...	100	0	0
Record of the Progress of Geology	100	0	0
Fermanagh Caves Exploration	5	0	0
Electrolysis of Metallic Solutions and Solutions of Compound Salts	25	0	0
Anthropometric Committee...	50	0	0
Natural History of Socotra ...	100	0	0
Calculation of Factor Tables for 5th and 6th Millions ...	150	0	0
Circulation of Underground Waters	10	0	0
Steering of Screw Steamers...	10	0	0
Improvements in Astronomical Clocks	30	0	0
Marine Zoology of South Devon	20	0	0
Determination of Mechanical Equivalent of Heat	12	15	6
Specific Inductive Capacity of Sprengel Vacuum	40	0	0
Tables of Sun-heat Coefficients	30	0	0
Datum Level of the Ordnance Survey	10	0	0
Tables of Fundamental Invariants of Algebraic Forms	36	14	9
Atmospheric Electricity Observations in Madeira	15	0	0
Instrument for Detecting Fire-damp in Mines	22	0	0
Instruments for Measuring the Speed of Ships	17	1	8
Tidal Observations in the English Channel	10	0	0
	£1080	11	11

1880.

	£	s.	d.
New Form of High Insulation Key	10	0	0
Underground Temperature ...	10	0	0
Determination of the Mechanical Equivalent of Heat	8	5	0
Elasticity of Wires	50	0	0
Luminous Meteors	30	0	0
Lunar Disturbance of Gravity	30	0	0
Fundamental Invariants	8	5	0
Laws of Water Friction	20	0	0
Specific Inductive Capacity of Sprengel Vacuum	20	0	0
Completion of Tables of Sun-heat Co-efficients	50	0	0
Instrument for Detection of Fire-damp in Mines	10	0	0
Inductive Capacity of Crystals and Paraffines	4	17	7
Report on Carboniferous Polyzoa	10	0	0
Caves of South Ireland	10	0	0
Viviparous Nature of Ichthyosaurus	10	0	0
Kent's Cavern Exploration...	50	0	0
Geological Record	100	0	0
Miocene Flora of the Basalt of North Ireland	15	0	0
Underground Waters of Permian Formations	5	0	0
Record of Zoological Literature	100	0	0
Table at Zoological Station at Naples	75	0	0
Investigation of the Geology and Zoology of Mexico	50	0	0
Anthropometry	50	0	0
Patent Laws	5	0	0
	£731	7	7

1881.

	£	s.	d.
Lunar Disturbance of Gravity	30	0	0
Underground Temperature ...	20	0	0
High Insulation Key	5	0	0
Tidal Observations	10	0	0
Fossil Polyzoa	10	0	0
Underground Waters	10	0	0
Earthquakes in Japan	25	0	0
Tertiary Flora	20	0	0
Scottish Zoological Station ...	50	0	0
Naples Zoological Station ...	75	0	0
Natural History of Socotra ...	50	0	0
Zoological Record	100	0	0
Weights and Heights of Human Beings	30	0	0
Electrical Standards	25	0	0
Anthropological Notes and Queries	9	0	0
Specific Refractions	7	3	1
	£476	3	1

1882.

	£	s.	d.
Tertiary Flora of North of Ireland	20	0	0
Exploration of Caves of South of Ireland	10	0	0
Fossil Plants of Halifax	15	0	0
Fundamental Invariants of Algebraical Forms	76	1	11
Record of Zoological Literature	100	0	0
British Fossil Polyzoa	10	0	0
Naples Zoological Station ...	80	0	0
Natural History of Timor-laut	100	0	0
Conversion of Sedimentary Materials into Metamorphic Rocks	10	0	0
Natural History of Socotra...	100	0	0
Circulation of Underground Waters	15	0	0
Migration of Birds	15	0	0
Earthquake Phenomena of Japan	25	0	0

	£	s.	d.
Geological Map of Europe ...	25	0	0
Elimination of Nitrogen by Bodily Exercise...............	50	0	0
Anthropometric Committee...	50	0	0
Photographing Ultra-Violet Spark Spectra	25	0	0
Exploration of Raygill Fissure............................	20	0	0
Calibration of Mercurial Thermometers	20	0	0
Wave-lengths Tables of Spectra of Elements...............	50	0	0
Geological Record...............	100	0	0
Standards for Electrical Measurements	100	0	0
Exploration of Central Africa	100	0	0
Albuminoid Substances of Serum	10	0	0
	£1126	1	11

General Meetings.

On Wednesday, August 23, at 8 P.M., in the Skating Rink, Sir John Lubbock, Bart., M.P., D.C.L., LL.D., F.R.S., F.L.S., F.G.S., resigned the office of President to C. W. Siemens, Esq., D.C.L., LL.D., F.R.S., F.C.S., M.I.C.E., who took the Chair, and delivered an Address, for which see page 1.

On Thursday, August 24, at 8 P.M., a Soirée took place in the Hartley Institution.

On Friday, August 25, at 8.30 P.M., in the Skating Rink, Professor Sir William Thomson, M.A., LL.D., D.C.L., F.R.S., delivered a Discourse on 'Tides.'

On Monday, August 28, at 8.30 P.M., in the Skating Rink, Professor H. N. Moseley, M.A., F.R.S., delivered a Discourse on 'Pelagic Life.'

On Tuesday, August 29, at 8 P.M., a Soirée took place in the Hartley Institution.

On Wednesday, August 30, at 2.30 P.M., the concluding General Meeting took place in the Skating Rink, when the Proceedings of the General Committee, and the Grants of Money for Scientific purposes, were explained to the Members.

The meeting was then adjourned to Southport. [The Meeting is appointed to commence on Wednesday, September 19, 1883.]

PRESIDENT'S ADDRESS.

ADDRESS

BY

C. WILLIAM SIEMENS,

D.C.L. (Oxon), LL.D. (Glasc. and Dubl.), Ph.D., F.R.S., F.C.S., Member Inst.C.E.,

PRESIDENT.

In venturing to address the British Association from this chair, I feel that I have taken upon myself a task involving very serious responsibility. The Association has for half a century fulfilled the important mission of drawing together, once every year, scientists from all parts of the country for the purpose of discussing questions of mutual interest, of endowing research, and of cultivating those personal relations which aid so powerfully in harmonising views, and in stimulating concerted action for the advancement of science.

A sad event casts a shadow over our gathering. While still mourning the irreparable loss Science had sustained in the person of Charles Darwin, whose bold conceptions, patient labour, and genial mind made him almost a type of unsurpassed excellence, telegraphic news reached Cambridge, just a month ago, to the effect that our General Secretary, Professor F. M. Balfour, had lost his life during an attempted ascent of the Aiguille Blanche de Péteret. Although only thirty years of age, few men have won distinction so rapidly and so deservedly. After attending the lectures of Dr. Michael Foster, he completed his studies of Biology under Dr. Anton Dohrn at the Zoological Station of Naples in 1875. In 1878 he was elected a Fellow, and in November last a member of Council of the Royal Society, when he was also awarded one of the Royal Medals for his embryological researches. Within a short interval of time Glasgow University conferred on him their honorary degree of LL.D., he was elected President of the Cambridge Philosophical Society, and after having declined very tempting offers from the Universities of Oxford and Edinburgh, he accepted a professorship of Animal Morphology created for him by his own University. Few men could have borne without hurt such a stream of honourable distinctions, but in young Balfour genius and independence of thought were happily blended with industry and personal modesty; these won for him the friendship, esteem, and admiration of all who knew him.

It affords me great satisfaction to qualify the sad impression produced

by this event, by the happy one of the safe return to these shores of that most persistent and disinterested Arctic explorer, Mr. B. Leigh Smith, together with his much enduring crew and valiant rescuers.

Since the days of the first meeting of the Association in York in 1831, great changes have taken place in the means at our disposal for exchanging views, either personally or through the medium of type. The creation of the railway system has enabled congenial minds to attend frequent meetings of those special Societies which have sprung into existence since the foundation of the British Association, amongst which I need only name here the Physical, Geographical, Meteorological, and Anthropological, cultivating abstract science, and the Institution of Mechanical Engineers, of Naval Architects, the Iron and Steel Institute, the Society of Telegraph Engineers and Electricians, the Gas Institute, the Sanitary Institute, and the Society of Chemical Industry, representing applied science. These meet at frequent intervals in London, whilst others, having similar objects in view, hold their meetings at the University towns, and at other centres of intelligence and industry throughout the country, giving evidence of great mental activity, and producing some of those very results which the founders of the British Association wished to see realised. If we consider further the extraordinary development of scientific journalism which has taken place, it cannot surprise us when we meet with expressions of opinion to the effect that the British Association has fulfilled its mission, and should now yield its place to those special Societies it has served to call into existence. On the other hand, it may be urged that the brilliant success of last year's Anniversary Meeting, enhanced by the comprehensive address delivered on that occasion by my distinguished predecessor in office, Sir John Lubbock, has proved, at least, that the British Association is not dead in the affections of its members, and it behoves us at this, the first ordinary gathering in the second half-century, to consider what are the strong points to rely upon for the continuance of a career of success and usefulness.

If the facilities brought home to our doors of acquiring scientific information have increased, the necessities for scientific inquiry have increased in a greater ratio. The time was when science was cultivated only by the few, who looked upon its application to the arts and manufactures as almost beneath their consideration; this they were content to leave in the hands of others, who, with only commercial aims in view, did not aspire to further the objects of science for its own sake, but thought only of benefiting by its teachings. Progress could not be rapid under this condition of things, because the man of pure science rarely pursued his inquiry beyond the mere enunciation of a physical or chemical principle, whilst the simple practitioner was at a loss how to harmonise the new knowledge with the stock of information which formed his mental capital in trade.

The advancement of the last fifty years has, I venture to submit, rendered theory and practice so interdependent, that an intimate union between them is a matter of absolute necessity for our future progress. Take, for instance, the art of dyeing, and we find that the discovery of new colouring matters derived from waste products, such as coal-tar, completely changes its practice, and renders an intimate knowledge of the science of chemistry a matter of absolute necessity to the practitioner. In telegraphy and in the new arts of applying electricity to lighting, to the transmission of power, and to metallurgical operations, problems arise at every turn, requiring for their solution not only an intimate acquaintance with, but a positive advance upon, electrical science as established by purely theoretical research in the laboratory. In general engineering the mere practical art of constructing a machine so designed and proportioned as to produce mechanically the desired effect, would suffice no longer. Our increased knowledge of the nature of the mutual relations between the different forms of energy makes us see clearly what are the theoretical limits of effect; these, although beyond our absolute reach, may be looked upon as the asymptotes to be approached indefinitely by the hyperbolic course of practical progress. Cases arise, moreover, where the introduction of new materials of construction, or the call for new effects, renders former rules wholly insufficient. In all these cases practical knowledge has to go hand in hand with advanced science in order to accomplish the desired end.

Far be it from me to think lightly of the ardent students of nature, who, in their devotion to research, do not allow their minds to travel into the regions of utilitarianism and of self-interest. These, the high priests of science, command our utmost admiration; but it is not to them that we can look for our current progress in practical science, much less can we look for it to the 'rule of thumb' practitioner, who is guided by what comes nearer to instinct than to reason. It is to the man of science who also gives attention to practical questions, and to the practitioner who devotes part of his time to the prosecution of strictly scientific investigations, that we owe the rapid progress of the present day, both merging more and more into one class, that of pioneers in the domain of nature. It is such men that Archimedes must have desired when he refused to teach his disciples the art of constructing his powerful ballistic engines, exhorting them to give their attention to the principles involved in their construction, and that Telford, the founder of the Institution of Civil Engineers, must have had in his mind's eye, when he (at the suggestion of Tredgold) defined civil engineering as 'the art of directing the great sources of power in nature.'

These considerations may serve to show that although we see the men of both abstract and applied science group themselves in minor bodies for the better prosecution of special objects, the points of contact between the different branches of knowledge are ever multiplying, all tending to form part of a mighty tree—the tree of modern science—under whose

ample shadow its cultivators will find it both profitable and pleasant to meet, at least once a year; and considering that this tree is not the growth of one country only, but spreads both its roots and branches far and wide, it appears desirable that at these yearly gatherings other nations should be more fully represented than has hitherto been the case. The subjects discussed at our meetings are without exception of general interest, but many of them bear an international character, such as the systematic collection of magnetic, astronomical, meteorological, and geodetical observations, the formation of a universal code for signalling at sea, and for distinguishing lighthouses, and especially the settlement of scientific nomenclatures and units of measurement, regarding all of which an international accord is a matter of the utmost practical importance.

As regards the measures of length and weight it is to be regretted that this country still stands aloof from the movement initiated in France towards the close of last century; but, considering that in scientific work metrical measure is now almost universally adopted, and that its use has been already legalised in this country, I venture to hope that its universal adoption for commercial purposes will soon follow as a matter of course. The practical advantages of such a measure to the trade of this country would, I am convinced, be very great, for English goods, such as machinery or metal rolled to current sections, are now almost excluded from the continental market, owing to the unit measure employed in their production. The principal impediment to the adoption of the metre consists in the strange anomaly that although it is legal to use that measure in commerce, and although a copy of the standard metre is kept in the Standards' Department of the Board of Trade, it is impossible to procure legalised rods representing it, and to use a non-legalised copy of a standard in commerce is deemed fraudulent. Would it not be desirable that the British Association should endeavour to bring about the use in this country of the metre and kilogramme, and, as a preliminary step, ask the Government to be represented on the International Metrical Commission, whose admirable establishment at Sèvres possesses, independently of its practical work, considerable scientific interest, as a well-found laboratory for developing methods of precise measurement?

Next in importance to accurate measures of length, weight, and time, stand, for the purposes of modern science, those of electricity.

The remarkably clear lines separating conductors from non-conductors of electricity, and magnetic from non-magnetic substances, enable us to measure electrical quantities and effects with almost mathematical precision; and, although the ultimate nature of this, the youngest scientifically investigated form of energy, is yet wrapt in mystery, its laws are the most clearly established, and its measuring instruments (galvanometers, electrometers, and magnetometers) are amongst the

most accurate in physical science. Nor could any branch of science or industry be named in which electrical phenomena do not occur, to exercise their direct and important influence.

If, then, electricity stands foremost amongst the exact sciences, it follows that its unit measures should be determined with the utmost accuracy. Yet, twenty years ago, very little advance had been made towards the adoption of a rational system. Ohm had, it is true, given us the fixed relations existing between electromotive force, resistance and quantity of current; Joule had established the dynamical equivalent of heat and electricity, and Gauss and Weber had proposed their elaborate system of absolute magnetic measurement. But these invaluable researches appeared only as isolated efforts, when, in 1862, the Electric Unit Committee was appointed by the British Association, at the instance of Sir William Thomson, and it is to the long-continued activity of this Committee that the world is indebted for a consistent and practical system of measurement, which, after being modified in details, received universal sanction last year by the International Electrical Congress assembled at Paris.

At this Congress, which was attended officially by the leading physicists of all civilised countries, the attempt was successfully made to bring about a union between the statical system of measurement that had been followed in Germany and some other countries, and the magnetic or dynamical system developed by the British Association, also between the geometrical measure of resistance, the (Werner) Siemens unit, that had been generally adopted abroad, and the British Association unit intended as a multiple of Weber's absolute unit, though not entirely fulfilling that condition. The Congress, while adopting the absolute system of the British Association, referred the final determination of the unit measure of resistance to an International Committee, to be appointed by the representatives of the several Governments; they decided to retain the mercury standard for reproduction and comparison, by which means the advantages of both systems are happily combined, and much valuable labour is utilised; only, instead of expressing electrical quantities directly in absolute measure, the Congress has embodied a consistent system, based on the Ohm, the Centimetre, the Gramme, and the Second, in which the units are of a value convenient for practical measurements. In this, which we must hereafter know as the 'practical system,' as distinguished from the 'absolute system,' the units are named after leading physicists, the Ohm, Ampère, Volt, Coulomb, and Farad.

I would venture to suggest that two further units might, with advantage, be added to the system decided on by the International Congress at Paris. The first of these is the unit of magnetic quantity or pole. It is of much importance, and few will regard otherwise than with satisfaction the suggestion of Clausius that the unit should be called a 'Weber,' thus retaining a name most closely connected with electrical measurements, and only omitted by the Congress in order to avoid the

risk of confusion in the magnitude of the unit current with which his name had been formerly associated.

The other unit I would suggest adding to the list is that of power. The power conveyed by a current of an Ampère through the difference of potential of a Volt is the unit consistent with the practical system. It might be appropriately called a Watt, in honour of that master mind in mechanical science, James Watt. He it was who first had a clear physical conception of power, and gave a rational method of measuring it. A Watt, then, expresses the rate of an Ampère multiplied by a Volt, whilst a horse-power is 746 Watts, and a Cheval de Vapeur 735.

The system of electro-magnetic units would then be:—

(1)	Weber, the unit of magnetic quantity				$= 10^8$	C.G.S. Units.
(2)	Ohm	,,	,,	resistance	$= 10^9$	,,
(3)	Volt	,,	,,	electromotive force	$= 10^8$	,,
(4)	Ampère	,,	,,	current	$= 10^{-1}$	,,
(5)	Coulomb	,,	,,	quantity	$= 10^{-1}$	,,
(6)	Watt	,,	,,	power	$= 10^7$	,,
(7)	Farad	,,	,,	capacity	$= 10^{-9}$	,,

Before the list can be looked upon as complete two other units may have to be added, the one expressing that of magnetic field, and the other of heat in terms of the electro-magnetic system. Sir William Thomson suggested the former at the Paris Congress, and pointed out that it would be proper to attach to it the name of Gauss, who first theoretically and practically reduced observations of terrestrial magnetism to absolute measure. A Gauss will, then, be defined as the intensity of field produced by a Weber at a distance of one centimetre; and the Weber will be the absolute C.G.S. unit strength of magnetic pole. Thus the mutual force between two ideal point-poles, each of one Weber strength held at unit distance asunder, will be one dyne; that is to say, the force which, acting for a second of time on a gramme of matter, generates a velocity of one centimetre per second.

The unit of heat has hitherto been taken variously as the heat required to raise a pound of water at the freezing-point through 1° Fahrenheit or Centigrade, or, again, the heat necessary to raise a kilogramme of water 1° Centigrade. The inconvenience of a unit so entirely arbitrary is sufficiently apparent to justify the introduction of one based on the electro-magnetic system, viz. the heat generated in one second by the current of an Ampère flowing through the resistance of an Ohm. In absolute measure its value is 10^7 C.G.S. units, and, assuming Joule's equivalent as 42,000,000, it is the heat necessary to raise 0·238 grammes of water 1° Centigrade, or, approximately, the $\frac{1}{1000}$th part of the arbitrary unit of a pound of water raised 1° Fahrenheit and the $\frac{1}{4000}$th of the kilogramme of water raised 1° Centigrade. Such a heat unit, if found acceptable, might with great propriety, I think, be called the Joule,

after the man who has done so much to develop the dynamical theory of heat.

Professor Clausius urges the advantages of the statical system of measurement for simplicity, and shows that the numerical values of the two systems can readily be compared by the introduction of a factor, which he proposes to call the critical velocity; this, Weber has already shown to be nearly the same as the velocity of light. It is not immediately evident how by the introduction of a simple multiple, signifying a velocity, the statical can be changed into dynamical values, and I am indebted to my friend Sir William Thomson for an illustration which struck me as remarkably happy and convincing. Imagine a ball of conducting matter so constituted that it can at pleasure be caused to shrink. Now let it first be electrified and left insulated with any quantity of electricity on it. After that, let it be connected with the earth by an excessively fine wire or a not perfectly dry silk fibre; and let it shrink just so rapidly as to keep its potential constant, till the whole charge is carried off. The velocity with which its surface approaches its centre is the electrostatic measure of the conducting power of the fibre. Thus we see how 'conducting power' is, in electrostatic theory, properly measured in terms of a velocity. Weber had shown how, in electromagnetic theory, the resistance, or the reciprocal of the conducting power of a conductor, is properly measured by a velocity. The critical velocity, which measures the conducting power in electrostatic reckoning and the resistance in electromagnetic, of one and the same conductor, measures the number of electrostatic units in the electromagnetic unit of electric quantity.

Without waiting for the assembling of the International Committee charged with the final determination of the Ohm, one of its most distinguished members, Lord Rayleigh, has, with his collaborateure, Mrs. Sidgwick, continued his important investigation in this direction at the Cavendish Laboratory, and has lately placed before the Royal Society a result which will probably not be surpassed in accuracy. His redetermination brings him into close accord with Dr. Werner Siemens, their two values of the mercury unit being 0·95418 and 0·9536 of the B.A. unit respectively, or 1 mercury unit $= 0{\cdot}9413 \times 10^9$ C.G.S. units.

Shortly after the publication of Lord Rayleigh's recent results, Messrs. Glazebrook, Dodds, and Sargant, of Cambridge, communicated to the Royal Society two determinations of the Ohm, by different methods; and it is satisfactory to find that their final values differ only in the fourth decimal, the figures being, according to

Lord Rayleigh . .	$1 \text{ Ohm} = 0{\cdot}98651 \dfrac{\text{Earth Quadrant}}{\text{Second}}$	
Messrs. Glazebrook, etc.	$= 0{\cdot}986271$	,,

Professor E. Wiedemann, of Leipzig, has lately called attention to the

importance of having the Ohm determined in the most accurate manner possible, and enumerates four distinct methods, all of which should unquestionably be tried with a view of obtaining concordant results, because upon its accuracy will depend the whole future system of measurement of energy of whatever form.

The word Energy was first used by Young in a scientific sense, and represents a conception of recent date, being the outcome of the labours of Carnot, Mayer, Joule, Grove, Clausius, Clerk-Maxwell, Thomson, Stokes, Helmholtz, Macquorn-Rankine, and other labourers, who have accomplished for the science regarding the forces in Nature what we owe to Lavoisier, Dalton, Berzelius, Liebig, and others, as regards Chemistry. In this short word Energy we find all the efforts in nature, including electricity, heat, light, chemical action, and dynamics, equally represented, forming, to use Dr. Tyndall's apt expression, so many 'modes of motion.' It will readily be conceived that when we have established a fixed numerical relation between these different modes of motion, we know beforehand what is the utmost result we can possibly attain in converting one form of energy into another, and to what extent our apparatus for effecting the conversion falls short of realising it. The difference between ultimate theoretical effect and that actually obtained is commonly called loss, but, considering that energy is indestructible, represents really secondary effect which we obtain without desiring it. Thus friction in the working parts of a machine represents a loss of mechanical effect, but is a gain of heat, and in like manner the loss sustained in transferring electrical energy from one point to another is accounted for by heat generated in the conductor. It sometimes suits our purpose to augment the transformation of electrical into heat energy at certain points of the circuit, when the heat rays become visible, and we have the incandescence electric light. In effecting a complete severance of the conductor for a short distance, after the current has been established, a very great local resistance is occasioned, giving rise to the electric arc, the highest development of heat ever attained. Vibration is another form of lost energy in mechanism, but who would call it a loss if it proceeded from the violin of a Joachim or a Norman-Neruda?

Electricity is the form of energy best suited for transmitting an effect from one place to another; the electric current passes through certain substances—the metals—with a velocity limited only by the retarding influence caused by electric charge of the surrounding dielectric, but approaching probably under favourable conditions that of radiant heat and light, or 300,000 kilometres per second; it refuses, however, to pass through oxidised substances, glass, gums, or through gases except when in a highly rarefied condition. It is easy therefore to confine the electric current within bounds, and to direct it through narrow channels of extraordinary length. The conducting wire of an Atlantic cable is such a narrow channel; it consists of a copper wire, or strand of

wires, 5 mm. in diameter, by nearly 5,000 kilometres in length, confined electrically by a coating of guttapercha about 4 mm. in thickness. The electricity from a small galvanic battery passing into this channel prefers the long journey to America in the good conductor, and back through the earth, to the shorter journey across the 4 mm. in thickness of insulating material. By an improved arrangement the alternating currents employed to work long submarine cables do not actually complete the circuit, but are merged in a condenser at the receiving station after having produced their extremely slight but certain effect upon the receiving instrument, the beautiful syphon recorder of Sir William Thomson. So perfect is the channel and so precise the action of both the transmitting and receiving instruments employed, that two systems of electric signals may be passed simultaneously through the same cable in opposite directions, producing independent records at either end. By the application of this duplex mode of working to the Direct United States cable under the superintendence of Dr. Muirhead, its transmitting power was increased from twenty-five to sixty words a minute, being equivalent to about twelve currents or primary impulses per second. In transmitting these impulse-currents simultaneously from both ends of the line, it must not be imagined, however, that they pass each other in the manner of liquid waves belonging to separate systems; such a supposition would involve momentum in the electric flow, and although the effect produced is analogous to such an action, it rests upon totally different grounds—namely, that of a local circuit at each terminus being called into action automatically whenever two similar currents are passed into the line simultaneously from both ends. In extending this principle of action quadruplex telegraphy has been rendered possible, although not yet for long submarine lines.

The minute currents here employed are far surpassed as regards delicacy and frequency by those revealed to us by that marvel of the present day, the telephone. The electric currents caused by the vibrations of a diaphragm acted upon by the human voice naturally vary in frequency and intensity according to the number and degree of those vibrations, and each motor current in exciting the electro-magnet forming part of the receiving instrument deflects the iron diaphragm occupying the position of an armature to a greater or smaller extent according to its strength. Savart found that the fundamental *la* springs from 440 complete vibrations in a second, but what must be the frequency and modulations of the motor current and of magnetic variations necessary to convey to the ear, through the medium of a vibrating armature, such a complex of human voices and of musical instruments as constitutes an opera performance? And yet such performances could be distinctly heard and even enjoyed, as an artistic treat, by applying to the ears a pair of the double telephonic receivers at the Paris Electrical Exhibition, when connected with a pair of transmitting instruments in front of the footlights of the Grand Opera. In connection with the telephone, and with its equally remarkable

adjunct the microphone, the names of Riess, Graham Bell, Edison, and Hughes will ever be remembered.

Considering the extreme delicacy of the currents working a telephone, it is obvious that those caused by induction from neighbouring telegraphic line wires would seriously interfere with the former, and mar the speech or other sounds produced through their action. To avoid such interference the telephone wires if suspended in the air require to be placed at some distance from telegraphic line wires, and to be supported by separate posts. Another way of neutralising interference consists in twisting two separately insulated telephone wires together, so as to form a strand, and in using the two conductors as a metallic circuit to the exclusion of the earth; the working current will, in that case, receive equal and opposite inductive influences, and will therefore remain unaffected by them. On the other hand two insulated wires instead of one are required for working one set of instruments; and a serious increase in the cost of installation is thus caused. To avoid this Mr. Jacob has lately suggested a plan of combining pairs of such metallic circuits again into separate working pairs, and these again with other working pairs, whereby the total number of telephones capable of being worked without interference is made to equal the total number of single wires employed. The working of telephones and telegraphs in metallic circuit has the further advantage that mutual volta induction between the outgoing and returning currents favours the transit, and neutralises on the other hand the retarding influence caused by change in underground or submarine conductors. These conditions are particularly favourable to underground line wires, which possess other important advantages over the still prevailing overground system, in that they are unaffected by atmospheric electricity, or by snowstorms and heavy gales, which at not very rare intervals of time put us back to pre-telegraphic days, when the letter-carrier was our swiftest messenger.

The underground system of telegraphs, first introduced into Germany by Werner Siemens in the years 1847–48, had to yield for a time to the overground system owing to technical difficulties; but it has been again resorted to within the last four years, and multiple land cables of solid construction now connect all the important towns of that country. The first cost of such a system is no doubt considerable (being about 38*l.* per kilometre of conductor as against 8*l.* 10*s.* the cost of land lines); but as the underground wires are exempt from frequent repairs and renewals, and as they insure continuity of service, they are decidedly the cheaper and better in the end. The experience afforded by the early introduction of the underground system in Germany was not, however, without its beneficial results, as it brought to light the phenomena of lateral induction, and of faults in the insulating coating, matters which had to be understood before submarine telegraphy could be attempted with any reasonable prospect of success.

Regarding the transmission of power to a distance the electric current

has now entered the lists in competition with compressed air, the hydraulic accumulator, and the quick running rope as used at Schaffhausen to utilise the power of the Rhine fall. The transformation of electrical into mechanical energy can be accomplished with no further loss than is due to such incidental causes as friction and the heating of wires; these in a properly designed dynamo-electric machine do not exceed ten per cent., as shown by Dr. John Hopkinson, and, judging from recent experiments of my own, a still nearer approach to ultimate perfection is attainable. Adhering, however, to Dr. Hopkinson's determination for safety's sake, and assuming the same percentage in reconverting the current into mechanical effect, a total loss of 19 per cent. results. To this loss must be added that through electrical resistance in the connecting line wires, which depends upon their length and conductivity, and that due to heating by friction of the working parts of the machine. Taking these as being equal to the internal losses incurred in the double process of conversion, there remains a useful effect of $100 - 38 = 62$ per cent., attainable at a distance, which agrees with experimental results, although in actual practice it would not be safe at present to expect more than 50 per cent. of ultimate useful effect, to allow for all incidental losses.

In using compressed air or water for the transmission of power, the loss cannot be taken at less than 50 per cent., and, as it depends upon fluid resistance, it increases with distance more rapidly than in the case of electricity. Taking the loss of effect in all cases as 50 per cent., electric transmission presents the advantage that an insulated wire does the work of a pipe capable of withstanding high internal pressure, which latter must be more costly to put down and to maintain. A second metallic conductor is required, however, to complete the electrical circuit, as the conducting power of the earth alone is found unreliable for passing quantity currents, owing to the effects of polarization; but as this second conductor need not be insulated, water or gas pipes, railway metals or fencing wire, may be called into requisition for this purpose. The small space occupied by the electro-motor, its high working speed, and the absence of waste products, render it specially available for the general distribution of power to cranes and light machinery of every description. A loss of effect of 50 per cent. does not stand in the way of such applications, for it must be remembered that a powerful central engine of best construction produces motive power with a consumption of two pounds of coal per horse-power per hour, whereas small engines distributed over a district would consume not less than five; we thus see that there is an advantage in favour of electric transmission as regards fuel, independently of the saving of labour and other collateral benefits, which more than compensate for interest on the cost of installation.

To agriculture, electric transmission of power seems well adapted for effecting the various operations of the farm and fields from one centre. Having worked such a system myself in combination with electric lighting

and horticulture for upwards of two years, I can speak with confidence of its economy, and of the facility with which the work is accomplished in charge of untrained persons.

As regards the effect of the electric light upon vegetation there is little to add to what was stated in my paper read before Section A last year, and ordered to be printed with the Report, except that in experimenting upon wheat, barley, oats, and other cereals sown in the open air, there was a marked difference between the growth of the plants influenced and those uninfluenced by the electric light. This was not very apparent till towards the end of February, when, with the first appearance of mild weather, the plants under the influence of an electric lamp of 4,000 candle power placed about 5 metres above the surface, developed with extreme rapidity, so that by the end of May they stood above 4 feet high, with the ears in full bloom, when those not under its influence were under 2 feet in height, and showed no sign of the ear.

In the electric railway first constructed by Dr. Werner Siemens, at Berlin, in 1879, electric energy was transmitted to the moving carriage or train of carriages, through the two rails upon which it moved, these being sufficiently insulated from each other by being placed upon well creosoted cross sleepers. At the Paris Electrical Exhibition the current was conveyed through two separate conductors making sliding or rolling contact with the carriage, whereas in the electric railway now in course of construction in the north of Ireland (which when completed will have a length of twelve miles) a separate conductor will be provided by the side of the railway, and the return circuit completed through the rails themselves, which in that case need not be insulated; secondary batteries will be used to store the surplus energy created in running downhill, to be restored in ascending steep inclines, and for passing roadways where the separate insulated conductor is not practicable. The electric railway possesses great advantages over horse or steam-power for towns, in tunnels, and in all cases where natural sources of energy, such as waterfalls, are available; but it would not be reasonable to suppose that it will in its present condition compete with steam propulsion upon ordinary railways. The transmission of power by means of electric conductors possesses the further advantage over other means of transmission that, provided the resistance of the rails be not very great, the power communicated to the locomotive reaches its maximum when the motion is at its minimum—that is, in commencing to work, or when encountering an exceptional resistance—whereas the utmost economy is produced in the normal condition of working when the velocity of the power-absorbing nearly equals that of the current-producing machine.

The deposition of metals from their solutions is perhaps the oldest of all useful applications of the electric current, but it is only in very recent times that the dynamo current has been practically applied to the refining of copper and other metals, as now practised at Birmingham and elsewhere, and upon an exceptionally large scale at Ocker, in Germany,

where the motive power is derived from a water-wheel. The dynamo machine there employed was exhibited at the Paris Electrical Exhibition by Dr. Werner Siemens, its peculiar feature being that the conductors upon the rotating armature consisted of solid bars of copper 30 mm. square, in section, which were found only just sufficient to transmit the large quantity of electricity of low tension necessary for this operation. One such machine consuming 4-horse power deposits about 300 kilogrammes of copper per 24 hours.

Electric energy may also be employed for heating purposes, but in this case it would obviously be impossible for it to compete in point of economy with the direct combustion of fuel for the attainment of ordinary degrees of heat. Bunsen and St. Claire De Ville have taught us, however, that combustion becomes extremely sluggish when a temperature of 1,800° C. has been reached, and for effects at temperatures exceeding that limit the electric furnace will probably find advantageous applications. Its specific advantage consists in being apparently unlimited in the degree of heat attainable, thus opening out a new field of investigation to the chemist and metallurgist. Tungsten has been melted in such a furnace, and 8 pounds of platinum have been reduced from the cold to the liquid condition in 20 minutes.

The largest and most extensive application of electric energy at the present time is to lighting, but, considering how much has of late been said and written for and against this new illuminant, I shall here confine myself to a few general remarks. Joule has shown that if an electric current is passed through a conductor the whole of the energy lost by the current is converted into heat; or, if the resistance be localised, into radiant energy, comprising heat, light, and actinic rays. Neither the low heat rays nor the ultra-violet of highest refrangibility affect the retina, and may be regarded as lost energy, the effective rays being those between the red and violet of the spectrum, which in their combination produce the effect of white light.

Regarding the proportion of luminous to non-luminous rays proceeding from an electric arc or incandescent wire, we have a most valuable investigation by Dr. Tyndall, recorded in his work on 'Radiant Heat.' Dr. Tyndall shows that the luminous rays from a platinum wire heated to its highest point of incandescence, which may be taken at 1,700° C., formed $\frac{1}{24}$th part of the total radiant energy emitted, and $\frac{1}{10}$th part in the case of an arc light worked by a battery of 50 Grove's elements. In order to apply these valuable data to the case of electric lighting by means of dynamo currents, it is necessary in the first place to determine what is the power of 50 Grove's elements of the size used by Dr. Tyndall, expressed in the practical scale of units as now established. From a few experiments lately undertaken for myself, it would appear that 50 such cells have an electro-motive force of 98·5 Volts, and an internal resistance of 13·5 Ohms, giving a current of 7·3 Ampères when the cells are short-circuited. The resistance of a regulator such as Dr.

Tyndall used in his experiments may be taken at 10 Ohms, the current produced in the arc would be $\frac{98\cdot5}{13\cdot5+10+1}=4$ Ampères (allowing one Ohm for the leads), and the power consumed $10\times4^2=160$ Watts; the light power of such an arc would be about 150 candles, and, comparing this with an arc of 3,308 candles produced by 1,162 Watts, we find that $\left(\frac{1162}{160}\right)$, i.e., 7·3 times the electric energy produce $\left(\frac{3308}{150}\right)$, i.e., 22 times the amount of light measured horizontally. If, therefore, in Dr. Tyndall's arc $\frac{1}{10}$th of the radiant energy emitted was visible as light, it follows that in a powerful arc of 3,300 candles, $\frac{1}{10}\times\frac{22\cdot0}{7\cdot3}$, or fully $\frac{1}{3}$, are luminous rays. In the case of the incandescent light (say a Swan light of 20 candle power) we find in practice that 9 times as much power has to be expended as in the case of the arc light; hence $\frac{1}{3}\times\frac{1}{9}=\frac{1}{27}$ part of the power is given out as luminous rays, as against $\frac{1}{24}$th in Dr. Tyndall's incandescent platinum—a result sufficiently approximate considering the wide difference of conditions under which the two are compared.

These results are not only of obvious practical value, but they seem to establish a fixed relation between current, temperature, and light produced, which may serve as a means to determine temperatures exceeding the melting point of platinum with greater accuracy than has hitherto been possible by actinimetric methods in which the thickness of the luminous atmosphere must necessarily exercise a disturbing influence. It is probably owing to this circumstance that the temperature of the electric arc as well as that of the solar photosphere has frequently been greatly over-estimated.

The principal argument in favour of the electric light is furnished by its immunity from products of combustion which not only heat the lighted apartments, but substitute carbonic acid and deleterious sulphur compounds for the oxygen upon which respiration depends; the electric light is white instead of yellow, and thus enables us to see pictures, furniture, and flowers as by daylight; it supports growing plants instead of poisoning them, and by its means we can carry on photography and many other industries at night as well as during the day. The objection frequently urged against the electric light, that it depends upon the continuous motion of steam or gas engines, which are liable to accidental stoppage, is met by the introduction into practical use of the secondary battery; this, although not embodying a new conception, has lately been greatly improved in power and constancy by Planté, Faure, Volckmar, Sellon, and others, and promises to accomplish for electricity what the gas-holder has done for the supply of gas and the accumulator for hydraulic transmission of power.

It can no longer be a matter of reasonable doubt, therefore, that electric lighting will take its place as a public illuminant, and that, even though its cost should be found greater than that of gas, it will be preferred for the lighting of drawing-rooms and dining-rooms, theatres

and concert-rooms, museums, churches, warehouses, show-rooms, printing establishments and factories, and also the cabins and engine-rooms of passenger steamers. In the cheaper and more powerful form of the arc light, it has proved itself superior to any other illuminant for spreading artificial daylight over the large areas of harbours, railway stations, and the sites of public works. When placed within a holophote the electric lamp has already become a powerful auxiliary in effecting military operations both by sea and land.

The electric light may be worked by natural sources of power such as waterfalls, the tidal wave, or the wind, and it is conceivable that these may be utilised at considerable distances by means of metallic conductors. Some five years ago I called attention to the vastness of those sources of energy, and the facility offered by electrical conduction in rendering them available for lighting and power-supply, while Sir William Thomson made this important matter the subject of his admirable address to Section A last year at York, and dealt with it in an exhaustive manner.

The advantages of the electric light and of the distribution of power by electricity have lately been recognised by the British Government, which has just passed a Bill through Parliament to facilitate the establishment of electrical conductors in towns, subject to certain regulating clauses to protect the interests of the public and of local authorities. Assuming the cost of electric light to be practically the same as gas, the preference for one or other will in each application be decided upon grounds of relative convenience, but I venture to think that gas-lighting will hold its own as the poor man's friend.

Gas is an institution of the utmost value to the artisan; it requires hardly any attention, is supplied upon regulated terms, and gives with what should be a cheerful light a genial warmth, which often saves the lighting of a fire. The time is moreover not far distant, I venture to think, when both rich and poor will largely resort to gas as the most convenient, the cleanest, and the cheapest of heating agents, and when raw coal will be seen only at the colliery or the gasworks. In all cases where the town to be supplied is within say 30 miles of the colliery, the gasworks may with advantage be planted at the mouth, or still better at the bottom of the pit, whereby all haulage of fuel would be avoided, and the gas, in its ascent from the bottom of the colliery, would acquire an onward pressure sufficient probably to impel it to its destination. The possibility of transporting combustible gas through pipes for such a distance has been proved at Pittsburg, where natural gas from the oil district is used in large quantities for heating purposes.

The quasi monopoly so long enjoyed by gas companies has had the inevitable effect of checking progress. The gas being supplied by meter, it has been seemingly to the advantage of the companies to give merely the prescribed illuminating power, and to discourage the invention of economical burners, in order that the consumption might reach a

maximum. The application of gas for heating purposes has not been encouraged, and is still made difficult in consequence of the objectionable practice of reducing the pressure in the mains during daytime to the lowest possible point consistent with prevention of atmospheric indraught. The introduction of the electric light has convinced gas managers and directors that such a policy is no longer tenable, but must give way to one of technical progress; new processes for cheapening the production and increasing the purity and illuminating power of gas are being fully discussed before the Gas Institute; and improved burners, rivalling the electric light in brilliancy, greet our eyes as we pass along our principal thoroughfares.

Regarding the importance of the gas supply as it exists at present, we find from a Government return that the capital invested in gasworks in England, other than those of local authorities, amounts to 30,000,000*l.*; in these 4,281,048 tons of coal are converted annually, producing 43,000 million cubic feet of gas, and about 2,800,000 tons of coke; whereas the total amount of coal annually converted in the United Kingdom may be estimated at 9,000,000 tons, and the by-products therefrom at 500,000 tons of tar, 1,000,000 tons of ammonia liquor, and 4,000,000 tons of coke, according to the returns kindly furnished me by the managers of many of the gasworks and corporations. To these may be added say 120,000 tons of sulphur, which up to the present time is a waste product.

Previous to the year 1856—that is to say, before Mr. W. H. Perkin had invented his practical process, based chiefly upon the theoretical investigations of Hofman, regarding the coal-tar bases and the chemical constitution of indigo—the value of coal-tar in London was scarcely a halfpenny a gallon, and in country places gas-makers were glad to give it away. Up to that time the coal-tar industry had consisted chiefly in separating the tar by distillation into naphtha, creosote, oils, and pitch. A few distillers, however, made small quantities of benzene, which had been first shown—by Mansfield, in 1849—to exist in coal-tar naphtha mixed with toluene, cumene, &c. The discovery, in 1856, of the mauve or aniline purple gave a great impetus to the coal-tar trade, inasmuch as it necessitated the separation of large quantities of benzene, or a mixture of benzene and toluene, from the naphtha. The trade was further increased by the discovery of the magenta or rosaniline dye, which required the same products for its preparation. In the meantime, carbolic acid was gradually introduced into commerce, chiefly as a disinfectant, but also for the production of colouring matter.

The next most important development arose from the discovery by Græbe and Liebermann that alizarine, the colouring principle of the madder root, was allied to anthracene, a hydrocarbon existing in coal-tar. The production of this colouring matter from anthracene followed, and is now one of the most important operations connected with tar-distilling. The success of the alizarine made in this manner has been so great that it has almost entirely superseded the use of madder, which is now culti-

vated to only a comparatively small extent. The most important colouring matters recently introduced are the azo-scarlets. They have called into use the coal-tar hydrocarbons, xylene and cumene. Naphthalene is also used in their preparation. These splendid dyes have replaced cochineal in many of its applications, and have thus seriously interfered with its use. The discovery of artificial indigo by Professor Baeyer is of great interest. For the preparation of this colouring matter toluene is required. At present artificial indigo does not compete seriously with the natural product; but should it eventually be prepared in quantity from toluene, a further stimulus will be given to the coal-tar trade.

The colour industry utilises even now practically all the benzene, a large proportion of the solvent naphtha, all the anthracene, and a portion of the naphthalene resulting from the distillation of coal-tar; and the value of the colouring matter thus produced is estimated by Mr. Perkin at 3,350,000*l.*

The demand for ammonia may be taken as unlimited, on account of its high agricultural value as a manure; and, considering the failing supply of guano and the growing necessity for stimulating the fertility of our soil, an increased production of ammonia may be regarded as a matter of national importance, for the supply of which we have to look almost exclusively to our gasworks. The present production of 1,000,000 tons of liquor yields 95,000 tons of sulphate of ammonia; which, taken at 20*l.* 10*s.* a ton, represents an annual value of 1,947,500*l.*

The total annual value of the gasworks' by-products may be estimated as follows:—

Colouring matter	£3,350,000
Sulphate of ammonia	1,947,500
Pitch (325,000 tons)	365,000
Creosote (25,000,000 gallons)	208,000
Crude carbolic acid (1,000,000 gallons)	100,000
Gas coke, 4,000,000 tons (after allowing 2,000,000 tons consumption in working the retorts) at 12*s.*	2,400,000
Total	£8,370,500

Taking the coal used, 9,000,000 tons, at 12*s.*, equal 5,400,000*l.*; it follows that the by-products alone exceed in value the coal used by very nearly 3,000,000*l.*

In using raw coal for heating purposes these valuable products are not only absolutely lost to us, but in their stead we are favoured with those semi-gaseous by-products in the atmosphere too well known to the denizens of London and other large towns as smoke. Professor Roberts has calculated that the soot in the pall hanging over London on a winter's day amounts to fifty tons, and that the carbon present as hydrocarbons and in the half-burnt form of carbonic oxide, a poisonous compound, resulting from the imperfect combustion of coal, may be taken as at least five times that amount. Mr. Aitken has shown, moreover, in an interesting paper communicated to the Royal Society of

Edinburgh, last year, that the fine dust resulting from the imperfect combustion of coal is mainly instrumental in the formation of fog; each particle of solid matter attracting to itself aqueous vapour; these globules of fog are rendered particularly tenacious and disagreeable by the presence of tar vapour, another result of imperfect combustion of raw fuel, which might be turned to much better account at the dye-works. The hurtful influence of smoke upon public health, the great personal discomfort to which it gives rise, and the vast expense it indirectly causes through the destruction of our monuments, pictures, furniture, and apparel, are now being recognised, as is evinced by the success of recent Smoke Abatement Exhibitions. The most effectual remedy would result from a general recognition of the fact that wherever smoke is produced, fuel is being consumed wastefully, and that all our calorific effects, from the largest down to the domestic fire, can be realised as completely and more economically, without allowing any of the fuel employed to reach the atmosphere unburnt. This most desirable result may be effected by the use of gas for all heating purposes, with or without the addition of coke or anthracite.

The cheapest form of gas is that obtained through the entire distillation of fuel in such gas-producers as are now largely used in working the furnaces of glass, iron, and steel works; but gas of this description would not be available for the supply of towns, owing to its bulk, about two-thirds of its volume being nitrogen. The use of water-gas, resulting from the decomposition of steam in passing through a hot chamber filled with coke, has been suggested, but this gas also is objectionable, because it contains, besides hydrogen, the poisonous and inodorous gas carbonic oxide, the introduction of which into dwelling-houses could not be effected without considerable danger. A more satisfactory mode of supplying heating separately from illuminating gas would consist in connecting the retort at different periods of the distillation with two separate systems of mains for the delivery of the respective gases, as has been proposed by me elsewhere. Experiments made some years ago by Mr. Ellisen of the Paris gasworks have shown that the gases rich in carbon, such as olefiant and acetylene, are developed chiefly during an interval of time beginning half an hour after the commencement and terminating at half the whole period of distillation, whilst during the remainder of the time marsh gas and hydrogen are chiefly developed, which, while possessing little illuminating power, are most advantageous for heating purposes. By resorting to improved means of heating the retorts with gaseous fuel, such as have been in use at the Paris gasworks for a considerable number of years, the length of time for effecting each distillation may be shortened from six hours, the usual period in former years, to four, or even three hours, as now practised at Glasgow and elsewhere. By this means a given number of retorts can be made to produce, in addition to the former quantity of illuminating gas of superior quality, a similar quantity of heating gas, resulting in a diminished cost of production

and an increased supply of the valuable by-products previously referred to. The quantity of both ammonia and heating gas may be further increased by the simple expedient of passing a streamlet of steam through the heated retorts towards the end of each operation, whereby the ammonia and hydrocarbons still occluded in the heated coke will be evolved, and the volume of heating gas produced be augmented by the products of decomposition of the steam itself. It has been shown that gas may be used advantageously for domestic purposes with judicious management even under present conditions, and it is easy to conceive that its consumption for heating would soon increase, perhaps tenfold, if supplied separately at, say, 1*s.* a thousand cubic feet. At this price gas would be not only the cleanest and most convenient, but also the cheapest form of fuel, and the enormous increase of consumption, the superior quality of the illuminating gas obtained by selection, and the proportionate increase of by-products, would amply compensate the gas company or corporation for the comparatively low price of the heating gas.

The greater efficiency of gas as a fuel results chiefly from the circumstance that a pound of gas yields in combustion 22,000 heat units, or exactly double the heat produced in the combustion of a pound of ordinary coal. This extra heating power is due partly to the freedom of the gas from earthy constituents, but chiefly to the heat imparted to it in effecting its distillation. Recent experiments with gas-burners have shown that in this direction also there is much room for improvement.

The amount of light given out by a gas flame depends upon the temperature to which the particles of solid carbon in the flame are raised, and Dr. Tyndall has shown that, of the radiant energy set up in such a flame, only the $\frac{1}{25}$th part is luminous; the hot products of combustion carry off at least four times as much energy as is radiated, so that not more than one hundredth part of the heat evolved in combustion is converted into light. This proportion could be improved, however, by increasing the temperature of combustion, which may be effected either by intensified air currents or by regenerative action. Supposing that the heat of the products of combustion could be communicated to metallic surfaces, and be transferred by conduction or otherwise to the atmospheric air supporting combustion in the flame, we should be able to increase the temperature accumulatively to any point within the limit of dissociation; this limit may be fixed at about 2,300° C., and cannot be very much below that of the electric arc. At such a temperature the proportion of luminous rays to the total heat produced in combustion would certainly be more than doubled, and the brilliancy of the light would at the same time be greatly increased. Thus improved, gas-lighting may continue its rivalry with electric lighting both as regards economy and brilliancy, and such rivalry must necessarily result in great public advantage.

In the domestic grate radiant energy of inferior intensity is required, and I for one do not agree with those who would like to see the open fireplace of this country superseded by the continental stove. The

advantages usually claimed for the open fireplace are, that it is cheerful, 'pokable,' and conducive to ventilation, but to these may be added another of even greater importance, viz. that the radiant heat which it emits passes through the transparent air without warming it, and imparts heat only to the solid walls, floor, and furniture of the room, which are thus constituted the heating surfaces of the comparatively cool air of the apartments in contact with them. In the case of stoves the heated air of the room causes deposit of moisture upon the walls in heating them, and gives rise to mildew and germs injurious to health. It is, I think, owing to this circumstance that upon entering an apartment one can immediately perceive whether or not it is heated by an open fireplace; nor is the unpleasant sensation due to stove-heating completely removed by mechanical ventilation; there is, moreover, no good reason why an open fireplace should not be made as economical and smokeless as a stove or hot-water apparatus.

In the production of mechanical effect from heat, gaseous fuel also presents most striking advantages, as will appear from the following consideration. When we have to deal with the question of converting mechanical into electrical effect, or *vice versâ*, by means of the dynamo-electrical machine, we have only to consider what are the equivalent values of the two forms of energy, and what precautions are necessary to avoid losses by the electrical resistance of conductors and by friction. The transformation of mechanical effect into heat involves no losses, except those resulting from imperfect installation, and these may be so completely avoided that Dr. Joule was able by this method to determine the equivalent values of the two forms of energy. But in attempting the inverse operation, of effecting the conversion of heat into mechanical energy, we find ourselves confronted by the second law of thermo-dynamics, which says, that whenever a given amount of heat is converted into mechanical effect, another but variable amount descends from a higher to a lower potential, and is thus rendered unavailable.

In the condensing steam engine this waste heat comprises that communicated to the condensing water, whilst the useful heat, or that converted into mechanical effect, depends upon the difference of temperature between the boiler and condenser. The boiler pressure is limited, however, by considerations of safety and convenience of construction, and the range of working temperature rarely exceeds 120° C. except in the engines constructed by Mr. Perkins, in which a range of 160° C., or an expansive action commencing at 14 atmospheres, has been adopted with considerable success, as appears from an able report on this engine by Sir Frederick Bramwell. To obtain more advantageous primary conditions we have to turn to the caloric or gas engine, because in them the coefficient of efficiency expressed by $\frac{T-T'}{T}$ may be greatly increased. This value would reach a maximum if the initial

absolute temperature T could be raised to that of combustion, and T′ reduced to atmospheric temperature, and these maximum limits can be much more nearly approached in the gas engine, worked by a combustible mixture of air and hydro-carbons, than in the steam engine.

Assuming, then, in an explosive gas engine a temperature of 1,500° C. at a pressure of 4 atmospheres, we should, in accordance with the second law of thermo-dynamics, find a temperature after expansion to atmospheric pressure of 600° C., and therefore a working range of $1500° - 600° = 900°$, and a theoretical efficiency of $\frac{900}{1500+274}$ = about one-half, contrasting very favourably with that of a good expansive condensing steam engine, in which the range is $150-30=120°$ C., and the efficiency $\frac{120}{150+274}=\frac{2}{7}$. A good expansive steam engine is therefore capable of yielding as mechanical work $\frac{2}{7}$th parts of the heat communicated to the boiler, which does not include the heat lost by imperfect combustion and that carried away in the chimney. Adding to these the losses by friction and radiation in the engine, we find that the best steam engine yet constructed does not yield in mechanical effect more than $\frac{1}{7}$th part of the heat energy residing in the fuel consumed. In the gas engine we have also to make reductions from the theoretical efficiency, on account of the rather serious loss of heat by absorption into the working cylinder, which has to be cooled artificially in order to keep its temperature down to a point at which lubrication is possible; this, together with frictional loss, cannot be taken at less than one-half, and reduces the factor of efficiency of the engine to $\frac{1}{4}$th.

It follows from these considerations that the gas or caloric engine combines the conditions most favourable to the attainment of maximum results, and it may reasonably be supposed that the difficulties still in the way of their application on a large scale will gradually be removed. Before many years have elapsed we shall find in our factories and on board our ships engines with a fuel consumption not exceeding 1 pound of coal per effective horse power per hour, in which the gas producer takes the place of the somewhat complex and dangerous steam boiler. The advent of such an engine and of the dynamo-machine must mark a new era of material progress at least equal to that produced by the introduction of steam power in the early part of our century. Let us consider what would be the probable effect of such an engine upon that most important interest of this country—the merchant navy.

According to returns kindly furnished me by the Board of Trade and 'Lloyds' Register of Shipping,' the total value of the merchant shipping of the United Kingdom may be estimated at 126,000,000*l.*, of which 90,000,000*l.* represent steamers having a net tonnage of 3,003,988 tons; and 36,000,000*l.* sailing vessels, of 3,688,008 tons. The safety of this vast amount of shipping, carrying about five-sevenths of our total imports

and exports, or 500,000,000*l.* of goods in the year, and of the more precious lives connected with it, is a question of paramount importance. It involves considerations of the most varied kind: comprising the construction of the vessel itself, and the material employed in building it; its furniture of engines, pumps, sails, tackle, compass, sextant, and sounding apparatus, the preparation of reliable charts for the guidance of the navigator, and the construction of harbours of refuge, lighthouses, beacons, bells, and buoys, for channel navigation. Yet notwithstanding the combined efforts of science, inventive skill, and practical experience—the accumulation of centuries—we are startled with statements to the effect that during last year as many as 1,007 British-owned ships were lost, of which fully two-thirds were wrecked upon our shores, representing a total value of nearly 10,000,000*l.* Of these ships 870 were sailing vessels and 137 steamers. The number of sailing vessels included in these returns being 19,325, and of steamers 5,505, it appears that the steamer is the safer vessel, in the proportion of 4·43 to 3·46; but the steamer makes on an average three voyages for one of the sailing ship taken over the year, which reduces the relative risk of the steamer as compared with the sailing ship per voyage in the proportion of 13·29 to 3·46. Commercially speaking, this large factor of safety in favour of steam-shipping is to a great extent counterbalanced by the value of the steamship, which bears to that of the sailing vessel per net carrying ton the proportion of 3 : 1, thus reducing the ratio in favour of steam shipping as 13·29 to 10·38, or in round numbers as 4 : 3. In testing this result by the charges of premium for insurance, the variable circumstances of distance, nature of cargo, season and voyage have to be taken into account; but judging from information received from shipowners and underwriters of undoubted authority, I find that the relative insurance paid for the two classes of vessel represents an advantage of 30 per cent. in favour of steam-shipping, agreeing very closely with the above deductions derived from statistical information.

In considering the question how the advantages thus established in favour of steam-shipping could be further improved, attention should be called in the first place to the material employed in their construction. A new material was introduced for this purpose by the Admiralty in 1876, when they constructed at Pembroke dockyard the two steam corvettes, the *Iris* and *Mercury*, of mild steel. The peculiar qualities of this material are such as to have enabled shipbuilders to save 20 per cent. in the weight of the ship's hull, and to increase to that extent its carrying capacity. It combines with a strength 30 per cent. superior to that of iron, such extreme toughness that in the case of collision the side of the vessel has been found to yield or bulge several feet without showing any signs of rupture, a quality affecting the question of sea risk very favourably. When to the use of this material there are added the advantages derived from a double bottom and from the division of the ship's hold by means of bulkheads of solid

construction, it is difficult to conceive how such a vessel could perish by collision either with another vessel or with a sunken rock. The spaces between the two bottoms are not lost, because they form convenient chambers for water ballast, but powerful pumps should in all cases be added to meet emergencies.

The following statement of the number and tonnage of vessels building and preparing to be built in the United Kingdom on the 30th of June last, which has been kindly furnished me by Lloyds', is of interest as showing that wooden ships are fast becoming obsolete, and that even iron is beginning to yield its place, both as regards steamers and sailing ships, to the new material mild steel; it also shows that by far the greater number of vessels now building are ships of large dimensions propelled by engine power:—

	Mild Steel		Iron		Wood		Total	
	No.	Tons gross	No.	Tons gross	No.	Tons gross	No.	Tons gross
Steam	89	159,751	555	929,921	6	460	650	1,090,132
Sailing	11	16,800	70	120,259	49	4,635	130	141,694
	100	176,551	625	1,050,180	55	5,095	780	1,232,826

If, to the improvements already achieved, could be added an engine of half the weight of the present steam engine and boilers, and working with only half the present expenditure of fuel, a further addition of 30 per cent. could be made to the cargo of an Atlantic propeller vessel—no longer to be called a steamer—and the balance of advantages in favour of such vessels would be sufficient to restrict the use of sailing craft chiefly to the regattas of this and neighbouring ports.

The admirable work on the 'British Navy,' lately published by Sir Thomas Brassey, the Civil Chief Lord of the Admiralty, shows that the naval department of this country is fully alive to all improvements having regard to the safety as well as to the fighting qualities of Her Majesty's ships of war, and recent experience goes far to prove that although high speed and manœuvring qualities are of the utmost value, the armour plate, which appeared to be fast sinking in public favour, is not without its value in actual warfare.

The progressive views perceptible in the construction of the navy are further evidenced in a remarkable degree in the hydrographic department. Captain Sir Frederick Evans, the hydrographer, gave us at York last year a very interesting account of the progress made in that department, which, while dealing chiefly with the preparation of charts showing the depth of water, the direction and force of currents, and the rise of tides near our shores, contains also valuable statistical information regarding the more general questions of the physical conditions of the sea, its temperature at various depths, its flora and fauna, as also the rainfall and the nature and force of prevailing winds. In connection with this subject the American Naval Department has taken an important part, under the guidance of Captain Maury and the Agassiz, father and son, whilst in this country the

persistent labours of Dr. William B. Carpenter deserve the highest commendation.

Our knowledge of tidal action has received a most powerful impulse through the invention of a self-recording gauge and tide-predicter, which will form the subject of one of the discourses to be delivered at our present meeting by its principal originator, Sir William Thomson; when I hope he will furnish us with an explanation of some extraordinary irregularities in tidal records, observed some years ago by Sir John Coode at Portland, and due apparently to atmospheric influence.

The application of iron and steel in naval construction rendered the use of the compass for some time illusory, but in 1839 Sir George Airy showed how the errors of the compass, due to the influence experienced from the iron of the ship, may be perfectly corrected by magnets and soft iron placed in the neighbourhood of the binnacle; but the great size of the needles in the ordinary compasses rendered the correction of the quadrantal errors practically unattainable. In 1876 Sir William Thomson invented a compass with much smaller needles than those previously used, which allows Sir George Airy's principles to be applied completely. With this compass correctors can be arranged so that the needle shall point accurately in all directions, and these correctors can be adjusted at sea from time to time, so as to eliminate any error which may arise through change in the ship's magnetism or in the magnetism induced by the earth through change of the ship's position. By giving the compass card a long period of free oscillation great steadiness is obtained when the ship is rolling.

Sir William Thomson has also enriched the art of navigation by the invention of two sounding machines; the one being devised for ascertaining great depths very accurately, in less than one-quarter the time formerly necessary, and the other for taking depths up to 130 fathoms without stopping the ship in its onward course. In both these instruments steel pianoforte wire is used instead of the hempen or silken lines formerly employed; in the latter machine the record of depth is obtained not by the quantity of wire run over its counter and brake wheel, but through the indications produced upon a simple pressure gauge consisting of an inverted glass tube, whose internal surface is covered beforehand with a preparation of chromate of silver, rendered colourless by the sea-water up to the height to which it penetrates. The value of this instrument for guiding the navigator within what he calls 'soundings' can hardly be exaggerated; with the sounding machine and a good chart he can generally make out his position correctly by a succession of three or four casts in a given direction at given intervals, and thus in foggy weather is made independent of astronomical observations and of the sight of lighthouses or the shore. By the proper use of this apparatus, accidents such as happened to the mail steamer *Mosel*, not a fortnight ago, would not be possible. As regards the value of the deep-sea instrument I can

speak from personal experience; on one occasion it enabled those in charge of the cable s.s. *Faraday* to find the end of an Atlantic cable, which had parted in a gale of wind, with no other indication of the locality than a single sounding, giving a depth of 950 fathoms. To recover the cable a number of soundings in the supposed neighbourhood of the broken end were taken, the 950 fathom contour line was then traced upon a chart, and the vessel thereupon trailed its grapnel two miles to the eastward of this line, when it soon engaged the cable 20 miles away from the point where dead reckoning had placed the ruptured end.

Whether or not it will ever be practicable to determine oceanic depths without a sounding line, by means of an instrument based upon gravimetric differences, remains to be seen. Hitherto the indications obtained by such an instrument have been encouraging, but its delicacy has been such as to unfit it for ordinary use on board a ship when rolling.

The time allowed me for addressing you on this occasion is wholly insufficient to do justice to the great engineering works of the present day, and I must therefore limit myself to making a short allusion to a few only of the more remarkable enterprises.

The great success, both technically and commercially, of the Suez Canal, has stimulated M. de Lesseps to undertake a similar work of even more gigantic proportions, namely, the piercing of the Isthmus of Panama by a ship canal, 40 miles long, 50 yards wide on the surface, and 20 yards at the bottom, upon a dead level from sea to sea. The estimated cost of this work is 20,000,000*l.*, and, more than this sum having been subscribed, it appears unlikely that political or climatic difficulties will stop M. de Lesseps in its speedy accomplishment. Through it, China, Japan, and the whole of the Pacific coasts will be brought to half their present distance, as measured by the length of voyage, and an impulse to navigation and to progress will be given which it will be difficult to over-estimate.

Side by side with this gigantic work, Captain Eads, the successful improver of the Mississippi navigation, intends to erect his ship railway, to take the largest vessels, fully laden and equipped, from sea to sea, over a gigantic railway across the Isthmus of Tehuantepec, a distance of 95 miles. Mr. Barnaby, the chief constructor of the navy, and Mr. John Fowler have expressed a favourable opinion regarding this enterprise, and it is to be hoped that both the canal and the ship railway will be accomplished, as it may be safely anticipated that the traffic will be amply sufficient to support both these undertakings.

Whether or not M. de Lesseps will be successful also in carrying into effect the third great enterprise with which his name has been prominently connected, the flooding of the Tunis-Algerian Chotts, thereby re-establishing the Lake Tritonis of the ancients, with its verdure-clad shores, is a question which could only be decided upon the evidence of

accurate surveys; but the beneficial influence of a large sheet of water within the African desert could hardly be matter of doubt.

It is with a feeling not unmixed with regret that I have to record the completion of a new Eddystone Lighthouse, in substitution for the *chef-d'œuvre* of engineering erected by John Smeaton more than 100 years ago. The condemnation of that structure was not, however, the consequence of any fault of construction, but was caused by inroads of the sea upon the rock supporting it. The new lighthouse, designed and executed by Mr., now Sir, James Douglass, engineer of Trinity House, has been erected in the incredibly short time of less than two years, and bids fair to be worthy of its famed predecessor. Its height above high water is 130 feet, as compared with 72 feet (the height of Smeaton's structure), which gives its powerful light a considerably increased range. The system originally suggested by Sir William Thomson some years ago, of distinguishing one light from another by flashes following at varied intervals, has been adopted by the Elder Brethren in this as in other recent lights in the modified form introduced by Dr. John Hopkinson, in which the principle is applied to revolving lights, so as to obtain a greater amount of light in the flash.

The geological difficulties which for some time threatened the accomplishment of the St. Gothard Tunnel have been happily overcome, and this second and most important sub-Alpine thoroughfare now connects the Italian railway system with that of Switzerland and the south of Germany, whereby Genoa will be constituted the shipping port for those parts.

Whether we shall be able to connect the English with the French railway system by means of a tunnel below the English Channel is a question that appears dependent, at this moment, rather upon military and political than technical and financial considerations. The occurrence of a stratum of impervious grey chalk, at a convenient depth below the bed of the Channel, minimises the engineering difficulties in the way, and must influence the financial question involved. The protest lately raised against its accomplishment can hardly be looked upon as a public verdict, but seems to be the result of a natural desire to pause, pending the institution of careful inquiries. Such inquiries have lately been made by a Royal scientific Commission, and will be referred for further consideration to a mixed Parliamentary Committee, upon whose Report it must depend whether the natural spirit of commercial enterprise has to yield in this instance to political and military considerations. Whether the Channel Tunnel is constructed or not, the plan proposed some years ago by Mr. John Fowler of connecting England and France by means of a ferry boat capable of taking railway trains would be a desideratum justified by the ever-increasing intercommunication between this and Continental countries.

The public inconvenience arising through the obstruction to traffic by a sheet of water is well illustrated by the circumstance that both the estuaries of the Severn and of the Mersey are being undermined in

order to connect the railway systems on the two sides, and that the Frith of Forth is about to be spanned by a bridge exceeding in grandeur anything as yet attempted by the engineer. The roadway of this bridge will stand 150 feet above high-water mark, and its two principal spans will measure a third of a statute mile each. Messrs. Fowler and Baker, the engineers to whom this great work has been entrusted, could hardly accomplish their task without having recourse to steel for their material of construction, nor need the steel used be of the extra mild quality particularly applicable for naval structures to withstand collision, for, when such extreme toughness is not required, steel of very homogeneous quality can be produced, bearing a tensile strain fully double that of iron.

The tensile strength of steel, as is well known, is the result of an admixture of carbon with the iron, varying between $\frac{1}{10}$th and 2 per cent., and the nature of this combination of carbon with iron is a matter of great interest both from a theoretical and practical point of view. It could not be a chemical compound which would necessitate a definite proportion, nor could a mere dissolution of the one in the other exercise such remarkable influence upon the strength and hardness of the resulting metal. A recent investigation by Mr. Abel has thrown considerable light upon this question. A definite carbide of iron is formed, it appears, soluble at high temperatures in iron, but separating upon cooling the steel gradually, and influencing only to a moderate degree the physical properties of the metal as a whole. In cooling rapidly there is no time for the carbide to separate from the iron, and the metal is thus rendered both hard and brittle. Cooling the metal gradually under the influence of great compressive force, appears to have a similar effect to rapid cooling in preventing the separation of the carbide from the metal, with this difference, that the effect is more equal throughout the mass, and that more uniform temper is likely to result.

When the British Association met at Southampton on a former occasion, Schönbein announced to the world his discovery of gun-cotton. This discovery has led the way to many valuable researches on explosives generally, in which Mr. Abel has taken a leading part. Recent investigations by him, in connection with Captain Noble, upon the explosive action of gun-cotton and gunpowder confined in a strong chamber, (which have not yet been published), deserve particular attention. They show that while by the method of investigation pursued about twenty years ago by Karolye (of exploding gunpowder in very small charges in shells confined within a large shell partially exhausted of air), the composition of the gaseous products was found to be complicated and liable to variation, the chemical metamorphosis which gun-cotton sustains, when exploded under conditions such as obtain in its practical application, is simple and very uniform. Among other interesting points noticed in this direction was the fact that, as in the case of gunpowder, the proportion of carbonic acid increases, while that of carbonic oxide diminishes with

the density of the charge. The explosion of gun-cotton, whether in the form of wool or loosely spun thread, or in the packed compressed form devised by Abel, furnished practically the same results if fired under pressure, that is, under strong confinement—the conditions being favourable to the full development of its explosive force; but some marked differences in the composition of the products of metamorphosis were observed when gun-cotton was fired by detonation. With regard to the tension exerted by the products of explosion, some interesting points were observed, which introduce very considerable difficulties into the investigation of the action of fired gun-cotton. Thus whereas no marked differences are observed in the tension developed by small charges and by very much larger charges of gunpowder having the same density (i.e. occupying the same volume relatively to the entire space in which they are exploded) the reverse is the case with respect to gun-cotton. Under similar conditions in regard to density of charge, 100 grammes of gun-cotton gave a measured tension of about 20 tons on the square inch, 1,500 grammes gave a tension of about 29 tons (in several very concordant observations), while a charge of 2·5 kilos gave a pressure of about 45 tons, this being the maximum measured tension obtained with a charge of gunpowder of five times the density of the above.

The extreme violence of the explosion of gun-cotton as compared with gunpowder when fired in a closed space was a feature attended with formidable difficulties. In whatever way the charge was arranged in the firing cylinder, if it had free access to the inclosed crusher gauge, the pressures recorded by the latter were always much greater than when means were taken to prevent the wave of matter suddenly set in motion from acting directly upon the gauge. The abnormal or wave-pressures recorded at the same time that the general tension in the cylinder was measured amounted in the experiment to 42·3 tons, when the general tension was recorded at 20 tons; and in another, when the pressure was measured at 29 tons, the wave-pressure recorded was 44 tons. Measurements of the temperature of explosion of gun-cotton showed it to be about double that of the explosion of gunpowder. One of the effects observed to be produced by this sudden enormous development of heat was the covering of the inner surfaces of the steel explosion-vessel with a network of cracks, small portions of the surface being sometimes actually fractured. The explosion of charges of gun-cotton up to 2·5 kilos in perfectly closed chambers, with development of pressures approaching to 50 tons on the square inch, constitutes alone a perfectly novel feat in investigations of this class.

Messrs. Noble and Abel are also continuing their researches upon fired gunpowder, being at present occupied with an inquiry into the influence exerted upon the chemical metamorphosis and ballistic effects of fired gunpowder by variation in its composition, their attention being directed especially to the discovery of the cause of the more or less considerable erosion of the interior surface of guns produced by the exploding charge—

an effect which, notwithstanding the application of devices in the building up of the charge specially directed to the preservation of the gun's bore, have become so serious that, with the enormous charges now used in our heavy guns, the erosive action on the surface of the bore produced by a single round is distinctly perceptible. As there appeared to be *primâ facie* reasons why the erosive action of powder upon the surface of the bore, at the high temperatures developed, should be at any rate in part due to its one component sulphur, Noble and Abel have made comparative experiments with powders of the usual composition and with others in which the proportion of sulphur was considerably increased, the extent of erosive action of the products escaping from the explosion vessel under high tension being carefully determined. With small charges a particular powder containing no sulphur was found to exert very little erosive action as compared with ordinary cannon powder; but another powder, containing the maximum proportion of sulphur tried (15 per cent.), was found equal to it under these conditions, and exerted very decidedly less erosive action than it, when larger charges were reached. Other important contributions to our knowledge of the action of fired gunpowder in guns, as well as decided improvements in the gunpowder manufactured for the very heavy ordnance of the present day, may be expected to result from a continuance of these investigations. Professor Carl Himly, of Kiel, having been engaged upon investigations of a similar nature, has lately proposed a gunpowder in which hydrocarbons (precipitated from solution in naphtha) take the place of the charcoal and sulphur of ordinary powder; this powder has amongst others the peculiar property of completely resisting the action of water, so that the old caution, 'Keep your powder dry,' may hereafter be unnecessary.

The extraordinary difference of condition, before and after its ignition, of such matter as constitutes an explosive agent, leads us up to a consideration of the aggregate state of matter under other circumstances. As early as 1776 Alexander Volta observed that the volume of glass was changed under the influence of electrification, by what he termed electrical pressure. Dr. Kerr, Govi, and others have followed up the same inquiry, which is at present continued chiefly by Dr. George Quincke, of Heidelberg, who finds that temperature, as well as chemical constitution of the dielectric under examination, exercises a determining influence upon the amount and character of the change of volume effected by electrification; that the change of volume may under certain circumstances be effected instantaneously as in flint glass, or only slowly as in crown glass, and that the elastic limit of both is diminished by electrification, whereas in the case of mica and of guttapercha an increase of elasticity takes place.

Still greater strides are being made at the present time towards a clearer perception of the condition of matter when particles are left some liberty to obey individually the forces brought to bear upon them. By the discharge of high tension electricity through tubes containing highly rarefied

gases (Geissler's tubes), phenomena of discharge were produced which were at once most striking and suggestive. The Sprengel pump afforded a means of pushing the exhaustion to limits which had formerly been scarcely reached by the imagination. At each step, the condition of attenuated matter revealed varying properties, when acted upon by electrical discharge and magnetic force. The radiometer of Crookes imported a new feature into these inquiries, which at the present time occupy the attention of leading physicists in all countries.

The means usually employed to produce electrical discharge in vacuum tubes was Ruhmkorff's coil; but Mr. Gassiot first succeeded in obtaining the phenomena by means of a galvanic battery of 3,000 Leclanché cells. Dr. De La Rue, in conjunction with his friend Dr. Hugo Müller, has gone far beyond his predecessors in the production of batteries of high potential. At his lecture 'On the Phenomena of Electric Discharge,' delivered at the Royal Institution in January 1881, he employed a battery of his own invention consisting of 14,400 cells (14,832 Volts), which gave a current of 0·054 Ampère, and produced a discharge at a distance of 0·71 inch between the terminals. During last year he increased the number of cells to 15,000 (15,450 Volts), and increased the current to 0·4 Ampère, or eight times that of the battery he used at the Royal Institution.

With the enormous potential and perfectly steady current at his disposal, Mr. De La Rue has been able to contribute many interesting facts to the science of electricity. He has shown, for example, that the beautiful phenomena of the stratified discharge in exhausted tubes are but a modification and a magnification of those of the electric arc at ordinary atmospheric pressure. Photography was used in his experiments to record the appearance of the discharge, so as to give a degree of precision otherwise unattainable in the comparison of the phenomena. He has shown that between two points the length of the spark, provided the insulation of the battery is efficacious, is as the square of the number of cells employed. Mr. De La Rue's experiments have proved that at all pressures the discharge in gases is not a current in the ordinary acceptation of the term, but is of the nature of a disruptive discharge. Even in an apparently perfectly steady discharge in a vacuum tube, when the strata as seen in a rapidly revolving mirror are immovable, he has shown that the discharge is a pulsating one; but, of course, the period must be of a very high order.

At the Royal Institution, on the occasion of his lecture, he produced, in a very large vacuum tube, an imitation of the Aurora Borealis; and he has deduced from his experiments that the greatest brilliancy of Aurora displays must be at an altitude of from thirty-seven to thirty-eight miles—a conclusion of the highest interest, and in opposition to the extravagant estimate of 281 miles, at which it had been previously put.

The President of the Royal Society has made the phenomena of electrical discharge his study for several years, and resorted in his important

experiments to a special source of electric power. In a note addressed to me, Dr. Spottiswoode describes the nature of his investigations much more clearly than I could venture to give them. He says: 'It had long been my opinion that the dissymmetry, shown in electrical discharges through rarefied gases, must be an essential element of every disruptive discharge, and that the phenomena of stratification might be regarded as magnified images of features always present, but concealed under ordinary circumstances. It was with a view to the study of this question that the researches by Moulton and myself were undertaken. The method chiefly used consisted in introducing into the circuit intermittence of a particular kind, whereby one luminous discharge was rendered sensitive to the approach of a conductor outside the tube. The application of this method enabled us to produce artificially a variety of phenomena, including that of stratification. We were thus led to a series of conclusions relating to the mechanism of the discharge, among which the following may be mentioned:—

'1. That a stria, with its attendant dark space, forms a physical unit of a striated discharge; that a striated column is an aggregate of such units formed by means of a step-by-step process; and that the negative glow is merely a localised stria, modified by local circumstances.

'2. That the origin of the luminous column is to be sought for at its negative end; that the luminosity is an expression of a demand for negative electricity; and that the dark spaces are those regions where the negative terminal, whether metallic or gaseous, is capable of exerting sufficient influence to prevent such demand.

'3. That the time occupied by electricity of either name in traversing tube is greater than that occupied in traversing an equal length of wire, but less than that occupied by molecular streams (Crookes' radiations) in traversing the tubes. Also that, especially in high vacua, the discharge from the negative terminal exhibits a durational character not found at the positive.

'4. That the brilliancy of the light with so little heat may be due in part to brevity in the duration of the discharge; and that for action so rapid as that of individual discharges, the mobility of the medium may count as nothing; and that for these infinitesimal periods of time gas may itself be as rigid and as brittle as glass.

'5. That striæ are not merely loci in which electrical is converted into luminous energy, but are actual aggregations of matter.

'This last conclusion was based mainly upon experiments made with an induction coil excited in a new way—viz. directly by an alternating machine, without the intervention of a commutator or condenser. This mode of excitement promises to be one of great importance in spectroscopic work, as well as in the study of the discharge in a magnetic field, partly on account of the simplification which it permits in the construction of induction coils, but mainly on account of the very great increase of strength in the secondary currents to which it gives rise.'

These investigations assume additional importance when we view them in connection with solar—I may even say stellar—physics, for evidence is augmenting in favour of the view that interstellar space is not empty, but is filled with highly attenuated matter of a nature such as may be put into our vacuum tubes. Nor can the matter occupying stellar space be said any longer to be beyond our reach for chemical and physical test. The spectroscope has already thrown a flood of light upon the chemical constitution and physical condition of the sun, the stars, the comets, and the far distant nebulæ, which latter have yielded spectroscopic photographs under the skilful management of Dr. Huggins, and Dr. Draper of New York. Armed with greatly improved apparatus the physical astronomer has been able to reap a rich harvest of scientific information during the short periods of the last two solar eclipses; that of 1879, visible in America, and that of May last, observed in Egypt by Lockyer, Schuster, and by Continental observers of high standing. The result of this last eclipse expedition has been summed up as follows: 'Different temperature levels have been discovered in the solar atmosphere; the constitution of the corona has now the possibility of being determined, and it is proved to shine with its own light. A suspicion has been aroused once more as to the existence of a lunar atmosphere, and the position of an important line has been discovered. Hydro-carbons do not exist close to the sun, but may in space between us and it.'

To me personally these reported results possess peculiar interest, for in March last I ventured to bring before the Royal Society a speculation regarding the conservation of solar energy, which was based upon the three following postulates, viz.:—

1. That aqueous vapour and carbon compounds are present in stellar or interplanetary space.

2. That these gaseous compounds are capable of being dissociated by radiant solar energy while in a state of extreme attenuation.

3. That the effect of solar rotation is to draw in dissociated vapours upon the polar surfaces, and to eject them after combustion back into space equatorially.

It is therefore a matter of peculiar gratification to me that the results of observation here recorded give considerable support to that speculation. The luminous equatorial extensions of the sun which the American observations revealed in such a striking manner (with which I was not acquainted when writing my paper) were absent in Egypt; but the outflowing equatorial streams (I suppose to exist) could only be rendered visible by reflected sunlight, or by electric discharge when mixed with dust produced by exceptional solar disturbances; and the occasional appearance of such luminous extensions would serve only to disprove the hypothesis entertained by some, that they are divided planetary matter, in which case their appearance should be permanent. Professor Langley, of Pittsburg, has shown by means of his bolometer, that the solar actinic rays are absorbed chiefly in the solar instead of in the

terrestrial atmosphere, and Captain Abney has found, by his new photometric method, that absorption, due to hydro-carbons, takes place somewhere between the solar and terrestrial atmosphere. In order to test this interesting result still further, he has lately taken his apparatus to the top of the Riffel with a view of diminishing the amount of terrestrial atmospheric air between it and the sun, and intends to bring a paper on this subject before Section A. Stellar space filled with such matter as hydro-carbon and aqueous vapour would establish a material continuity between the sun and his planets, and between the innumerable solar systems of which the universe is composed. If chemical action and reaction can further be admitted, we may be able to trace certain conditions of thermal dependence and maintenance, in which we may recognise principles of high perfection, applicable also to comparatively humble purposes of human life.

We shall thus find that in the great workshop of nature there are no lines of demarcation to be drawn between the most exalted speculation and commonplace practice, and that all knowledge must lead up to one great result, that of an intelligent recognition of the Creator through His works. So then, we members of the British Association and fellow-workers in every branch of science may exhort one another in the words of the American bard who has so lately departed from amongst us:—

Let us then be up and doing,
With a heart for any fate;
Still achieving, still pursuing,
Learn to labour and to wait.

REPORTS

ON THE

STATE OF SCIENCE.

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Report of the Committee, consisting of Professor SYLVESTER, Professor CAYLEY, *and the* Rev. GEORGE SALMON, D.D., *appointed in connection with the Calculation of Tables of Fundamental Invariants of Binary Quantics.*

IT has been thought advisable to extend the calculation of tables of invariants (proper) to ternary systems of binary quantics, and the following systems have been selected for the purpose.

Two quadrics and a quartic; a quadric and two quartics; three quartics; a quadric, cubic, and quartic: say the systems (2) (2) (4); (2) (4) (4); (4) (4) (4); (2) (3) (4).

By far the most considerable amount of the work belongs to the calculations connected with the last-named system.

The entire work covers 52 sheets of paper of dimensions 31 in. by 23 in., divided into 93×69, i.e. 6417 $\frac{1}{3}$rd-inch squares, each enclosing one numerical coefficient; the total number of such spaces, of which only a moderately small fraction remains vacant, being accordingly 333,684.

The work of compilation was actually performed by Messrs. Healy and Durfee (fellows), under the able superintendence of Dr. F. Franklin (associate) of the Johns Hopkins University—who is of opinion that at least nine-tenths of the labour and time that would otherwise have been required for the calculations has been saved by the method of operation above indicated: a method called by its presumable inventor or originator, Professor Sylvester, the method of cage-work or occlusion, which has also been found by Dr. Franklin applicable with very considerable advantage to certain operose astronomical computations with which he has been entrusted in connection with one of the public departments in Washington.

The leading results will be published in the 'American Journal of Mathematics' in a form similar to that of the tables of like kind, calculated at the expense of the British Association, which have already appeared there.

It is sufficient for present purposes to state that the fundamental invariants (the absolute constant not included) for the systems (2) (2) (4); (2) (4) (4); (4) (4) (4); (2) (3) (4) are respectively 19, 29, 25 and 64 in number; the first, second, and fourth of these totals, viz. 19, 29, 64, it will be noticed, are very nearly the same as the numbers of invariants of the systems (1) (2) (4); (1) (4) (4); (1) (3) (4) which are, as is well known, identical with the numbers 18, 28, 61, of the in- and co-variants belonging to the quadri-quartic, quarto-quartic, and cubo-quartic systems respectively.

It may also be stated that the invariants of the three systems in which only quadrics or quartics are contained are all unique for a given type; that is, in each of the three systems there is never more than a single invariant of given degrees in the coefficients of the three constituent quantics respectively.

Report (provisional) of the Committee, consisting of Mr. ROBERT H. SCOTT (*Secretary*), Mr. J. NORMAN LOCKYER, Professor H. J. S. SMITH, Professor G. G. STOKES, Professor BALFOUR STEWART, *and* Mr. G. J. SYMONS, *appointed for the purpose of co-operating with the Meteorological Society of the Mauritius in their proposed publication of Daily Synoptic Charts of the Indian Ocean from the year* 1861.

THE Committee have no report to submit, for it appears from the latest letters received from Dr. Meldrum that the actual printing off of the proposed Synoptic Charts for the Indian Ocean has not yet been commenced.

No expense has therefore been incurred as yet, and there has been no occasion to apply for any portion of the grant of 50*l.* made at the York meeting.

However, the Meteorological Society of the Mauritius contemplates the issue of the charts in the course of the coming year, so that the Committee request that they may be re-appointed, and the grant renewed.

Report of Committee, consisting of Captain ABNEY (*Secretary*), Professor W. G. ADAMS, Professor G. C. FOSTER, Professor Lord RAYLEIGH, Mr. PREECE, Professor SCHUSTER, Professor DEWAR, Professor VERNON HARCOURT, *and* Professor AYRTON, *for the purpose of fixing a Standard of White Light.*

As the experiments conducted by the Committee are still in progress, the Report cannot be ready for presentation this year.

Report on Recent Progress in Hydrodynamics. *By* W. M. Hicks, *M.A.*

Part II. Special Problems.

This second part of the report will deal with matters of more purely mathematical interest than the first, and will chiefly comprise the consideration of those particular solutions of the equation $\nabla^2\phi = o$, which satisfy conditions given over the boundaries of various surfaces, and the determination of the effective inertia of the surrounding fluid when solids of different forms move in it. The problems here considered may be regarded in different lights, according as the investigator has accustomed himself to think from a hydrodynamical, an electrical, or a conduction of heat point of view. Consequently, it will be found that several of the hydrodynamical solutions will be found in papers with electrical or other titles. In the following the motion of a perfect fluid in (*a*) two and (*b*) three dimensions, and (*c*) of a viscous fluid, will be taken in order, the latter from a mathematical standpoint, without reference to the experimental researches which have been carried out by a large number of investigators. But, before passing on, it may be well here to add a few remarks in the way of correction or addition to the first part of the Report published last year.

Professor Larmor has drawn my attention to the fact that the theory of the ignoration of co-ordinates, mentioned on page 60, is essentially due to Routh, who gave the complete theory in his Adams' prize essay 'On the Stability of Motion' (p. 60). The application of the theory to fluid motion is due to Thomson and Tait. The statement on p. 65, 'that the circulation round any closed curve in the fluid is equal to twice the surface integral of the resolved part of the vortices perpendicular to the surface over any surface whose boundary is the curve,' is a theorem due to Thomson, is not correct. Beltrami[1] states that Hankel gave the theorem in 1861, in a paper[2] which I have not been able to obtain; but it seems to have been given by Stokes, in 1854, in a Smith's prize[3] paper for that year. This would, therefore, appear to be the first publication.

In the consideration of viscosity on p. 81 a notice of a paper by Helmholtz[4] ought to have been given, in which he proves two general theorems. These are that, if squares and products of the velocity be neglected, and if the fluid be not supposed to glide over the surfaces of bodies immersed in it, then, (1) if the motion be steady, the currents in the viscous fluids are so distributed that the loss of energy due to viscosity is a minimum, on the supposition that the velocities along the boundaries of the fluid are given; and (2) a floating body is in equilibrium in a viscous fluid flowing with slow steady motion, if the loss is also a minimum, when the velocities of the fluid along the surface of the

[1] *Sui principii fondamentali dell' idrodinamica razionale.*

[2] *Zur allgemeinen Theorie der Bewegung der Flüssigkeiten.* Gött. 1861. Now out of print.

[3] See *Camb. Univ. Calendar* for 1854, p. 415.

[4] 'Zur Theorie der stationären Ströme in reibenden Flüssigkeiten,' *Verh. naturhist. Vereins.* Heidelberg. V. p. 1. (1868.) Also Collected Works, i. p. 223.

body are varied in the same way as if the solid were to have one of its possible motions.

On the same page it should be noted that the theory of similitude given by Helmholtz had already, more than twenty years before, been stated by Stokes,[1] though not so fully as to include different coefficients of gliding over the surfaces of bodies immersed. The applications by Helmholtz are new.

On page 80, line 20, for 'its rate of variation,' read, 'the rate of variation of the energy.'

The following letters have throughout, unless specially noticed, the meanings here given, viz.:—

Where m denotes the mass of a body, m' denotes the mass of the fluid displaced by it.

ρ denotes the density of the fluid.
ϕ ,, ,, velocity potential.
ψ ,, ,, stream function.
μ' ,, ,, coefficient of viscosity.
μ ,, ,, kinematic coefficient of viscosity $= \mu'/\rho$.

a. *Motion in Two Dimensions.*

Sources and Sinks.—The simplest motion possible is that where fluid moves in an infinite plane, streaming *from* certain points (sources) and *into* others (sinks). Its importance consists in this, that all potential functions can be considered as due to certain distributions of sources or sinks at definite points, or along certain lines and surfaces, as has been shown by Stokes.[2] Regarded from this point of view they have been called the 'Green's functions of the given distribution of matter.' Many examples will occur in the succeeding pages of their application. W. R. Smith[3] has developed some of the general properties of the stream-lines and equipotential lines for two dimensional motion when the number of singular points is finite and all are of the same magnitude. When the system is complete, *i.e.* when the numbers of sources and sinks are equal, the degrees of both the stream-lines and equipotential lines are equal to the whole number of singular points. When the numbers are unequal this is still true for the stream-lines, but the degree of the equipotential line is double the greater number. The general nature of the lines is clearly different, according as the system is complete or not. In the former case one stream-line goes to infinity, and is, at most, of a degree one less than the number of singular points, whilst if the system be not complete, every complete stream-line has a number of asymptotes equal to the difference of the numbers of sources and sinks. More particularly he considers the cases of two, three, and four singular points, and gives figures when they are at the corners of a rectangle and of a regular trapezium. Cases of the same kind have also been noticed by Kirchhoff[4]

[1] *Camb. Phil. Trans.* ix.

[2] 'On the internal distribution of matter which shall produce a given potential at the surfaces of a gravitating mass,' *Proc. Roy. Soc.*, xv., p. 482; and *Phil. Mag.*, xxxiv. p. 235 (1867).

[3] 'On the flow of electricity in conducting surfaces,' *Proc. Roy. Soc. Edin.*, vii. p. 79. 1870.

[4] 'Ueber den Durchgang eines elektrischen Stromes durch eine Ebene, insbesondere durch eine kreisförmige,' *Pogg. Ann.* lxiv. p. 497, or *Gesam. Abhand.* p. 1.

(1845), Quincke[1] (1856), Auerbach[2] (1878), and Chwolson[3] (1878), from the electrical point of view.

As sources and sinks may be regarded as the origin of all non-cyclic motion, so may the vortex-filament be looked upon as the basis for cyclic motion. The cases of one or two vortices, discovered by Helmholtz, have been already referred to.[4] When more than two are present the general treatment of their motions involves mathematical difficulties of calculation, though the theory is quite straightforward. Particular cases have been worked out with much detail by W. Gröbli[5] (1877), in a paper which has much interest from the number of figures it contains illustrating the paths in certain cases. He considers the cases (1) of three vortices (α) equal, but one of different sign from the other two, (β) equal and of the same sign, (γ) two equal and opposite and double the third; also the conditions that they shall always lie at the angles of a triangle (δ) of constant size and form, (ϵ) of constant form (ζ) with two equal sides; (2) of four equal vortices with a plane of symmetry—which comes to the same thing as two equal vortices in an infinite fluid bounded by a plane; and (3) of $2n$ equal vortices with n planes of symmetry, or one vortex in the fluid bounded by two planes inclined at an angle π/n. In this last case each describes the Cotes' spiral, $r \sin n\theta = \text{const.}$ It would lead us too far to describe more fully the results arrived at, which, after all, are only particular cases of the general problem. The last question has also been discussed by Greenhill[6] (1878), who shows that a vortex of strength m, in an angle π/n, will describe its Cotes' spiral as if it were a particle under the attraction of a force varying inversely as the cube of the distance from the angle, and strength $= \frac{1}{4}(n^2 - 1)\,m^2$.

The theory of the fluid motions resulting when portions of planes are held in a stream has been referred to in the last report,[7] and it will be sufficient here to give for reference the cases already solved. The case of fluid flowing from an infinite space into a canal bounded by two parallel planes is historically the most interesting, being the first example of discontinuous motion which yielded to the genius of Helmholtz.[8] The only other solutions at present known are those discovered by Kirchhoff.[9] These reduce to special cases of the two general problems (1) where fluid issues from between two straight lines drawn in any direction from two points, and (2) where a straight line is opposed in a stream of fluid at any angle. The solution of the equation of continuity for all the space outside

[1] 'Ueber die Verbreitung eines elektrischen Stromes in Metallplatten,' *Pogg. Ann.* xcvii. p. 382. He considers space bounded by two infinite lines at right angles.

[2] 'Ueber die Verbreitung stationärer electrischer Ströme in leitenden Flächen,' *Wied. Ann.* iii. p. 498.

[3] 'Ueber das Problem der Stromverzweigung in einer ebenen Platte,' *Schlöm. Z.* xxiii, p. 47.

[4] *Brit. Ass. Rep.*, 1881, p. 64.

[5] 'Specielle Probleme über die Bewegung geradliniger paralleler Wirbelfäden,' *Inaug. Diss. Gött.* pp. 86; also, *Vierteljahrschrift der naturforschenden Gesellschaft in Zürich*, xxii.

[6] 'Plane vortex motion,' *Quart. Jour.* xv. p. 10.

[7] *Brit. Ass. Rep.* 1881, p. 69.

[8] 'Ueber discontinuirliche Flüssigkeitsbewegungen,' *Monatsb. Akad. Berl.* 1868, p. 215. *Phil. Mag.* (4) xxxvi. p. 337; also reprinted in Helmholtz' *Wissen. Abhand.* Bd. i. p. 146.

[9] 'Zur Theorie freier Flüssigkeitsstrahlen,' *Crelle*, lxx. p. 289; and reprinted in *Ges. Werke*, p. 416, and *Vorlesungen ü. Math. Physik.* Vorles. 21, 22.

a line can be deduced from the case of the ellipse referred to below. It is of importance from an electrical point of view, but is only of purely mathematical interest as far as hydrodynamics is concerned.

Passing on now to spaces bounded by straight lines, we have to notice the cases of two parallel lines, triangles, and rectangles. Sources and sinks between parallel planes have been discussed by the writer, but they may be regarded as limiting cases of the rectangle, which is referred to below. When the triangle is equilateral, the motion for a rotation was discovered by F. D. Thomson,[1] and Stokes[2] has shown that for this the effective moment of inertia of the equivalent solid is two-fifths of that of the solidified fluid. The potential and stream functions for a vortex inside such a triangle have been given by Greenhill,[3] and the path described by the vortex, also the same functions when there is a source at one corner and a sink at the other. For the right-angled isosceles triangle the case for a source and sink at the base angles have been given by the writer,[4] and are, I believe, the only ones solved for this triangle. If the vertex of a triangle move off to infinity perpendicular to the base, we get the space bounded on three sides by two infinite parallel lines, and a third line perpendicular to them. The potential and stream function for a source, or a vortex (electric point) in such a space are given in the same paper, as well as figures illustrating them in particular cases. This may be regarded as a limiting case of the rectangle, to which we now proceed.

This form has received much attention from the time when Stokes[5] first discussed it in 1843. He determined the velocity potential for the internal motion when the boundary rotates, in the form of an infinite series, and in the same form evaluated the moment of inertia of the equivalent solid. His method is based on determining the coefficients of an infinite series to represent the motion of rotation of two opposite sides when the other pair are at rest, and then combining them for the whole motion. The same problem is considered in 'Thomson and Tait's Natural Philosophy.'[6] Ferrers[7] (1878) attacks the question differently. He first shows that if the density of matter at every part of a plane be given by $\rho \cos mx \cos ny$, its potential is $4\pi\rho \cos mx \cos ny \,/(m^2 + n^2)$. Now the analytical conditions for the stream function of the motion of fluid in a rotating rectangle are the same as for the potential for a distribution of matter of density $+1$, and -1, in alternate equal rectangles. This density is expressed as the product of two Fourier's series, and the before-mentioned theorem applied. Greenhill[8] (1878) gives expressions for the velocities at any point in a very compact form as definite integrals of certain elliptic functions of the position of the point. He arrives at this

[1] 'On certain cases of fluid motion,' *Ox. Cam. and Dub. Mess. Math.* iii. p. 238.

[2] Reprint of papers, p. 65.

[3] 'Solutions by means of elliptic functions of some problems in the conduction of electricity and of heat in plane figures,' *Quart. Jour.* xvii. p. 284.

[4] 'On velocity and electric potentials between parallel planes,' *Quart. Jour.* xv. p. 313.

[5] 'On some cases of fluid motion,' *Trans. Camb. Phil. Soc.* viii. p. 105 (1843). Supplement to a memoir 'On some cases of fluid motion' (1846), *Ibid.* p. 409. 'On the critical values of the sums of periodic series' (1849), *Ibid.* p. 533, sec. iv. In the reprint of papers these are vol. i. pp. 60, 188, and 288.

[6] Vol. i. 1st ed. p. 541.

[7] 'Solution of certain questions in potentials and motion of liquids,' *Quart. Jour.* xv. p. 83.

[8] 'Notes on hydrodynamics: on the motion of water in a rotating rectangular prism,' *Quart. Jour.* xv. 144.

result by taking the series for the velocity and stream functions given in Thomson and Tait, and expressing the series for the velocities derived from them in the above way. The upper limits of the integrals are the co-ordinates of the point. Definite integral expressions, with constant limits for the velocity and stream functions, and the velocities, have been determined by myself,[1] by taking the values of these functions for a source inside a rectangle, and distributing sources and sinks over the sides of the rectangle, proportional to the normal motion of the boundary at the point.

The two functions for a source inside a rectangle were first (1865) determined by Jochmann[2] by summation of the corresponding functions for the whole set of images of the source. They depend in general on the Theta functions, and for particular positions take simple forms. The same problem for vortices has been solved by Greenhill,[3] who has also found the equation to the path of a single vortex inside the boundary. The form is so simple that I venture to reproduce it here. If the origin be at the centre, and if K : K′ be the ratio of the sides, the equation to the path of a vortex is $\mathrm{ctn}^2(\mathrm{K}x/a, k) + \mathrm{ctn}^2(\mathrm{K}'y/b, k') = \text{const}$, whilst, if the vortex is at the centre, the stream-lines are $\mathrm{cn}(\mathrm{K}x/a, k)\,\mathrm{cn}(\mathrm{K}'y/b, k') = \tanh\psi/m$.

The Circle.—This naturally was amongst one of the first boundaries for which the velocity potential was found. It was given by Stokes[4] in 1843 as a particular case of the general motion of the surfaces of two concentric circles, and he showed that the mass of the equivalent solid was equal to that of the fluid displaced. A very full discussion of the motion of the particles of the fluid, by Clerk-Maxwell,[5] will be found in the 'Proceedings' of the Mathematical Society, a discussion which is rendered all the more instructive from the figures which accompany it. Both these papers treat of non-cyclic motion; but the space in two dimensions about a circle being cyclic, admits of a many-valued velocity potential. Rayleigh[6] and Greenhill[7] have shown that when there is a cyclic motion about the circle it will itself move in a circle in the same direction as that motion, whilst the latter has shown that if it also moves under the action of gravity it will describe a trochoid. The image of a source in a circle has long been known, and that of a vortex is a natural corollary.

Two Circles.—This is another boundary for which we owe the first discussion to Stokes[8] (1843). He considered them concentric, with any general motion of the points of the surface, and in particular for the

[1] 'On velocity and electric potentials between parallel planes,' *Quart. Jour.* xv. p. 274.

[2] 'Ueber einige Aufgaben, welche die Theorie des logarithmischen Potentials und den Durchgang eines constanten elektrischen Stroms durch eine Ebene betreffen.' *Schlöm Z.* x. pp. 48 and 89. They are also given in my paper referred to above, and a particular case when the source and sink bisect opposite sides of the rectangle by Betti. *Sopra la distribuzione delle correnti elettriche in uno lastra rettangolare.* N. Cim. (2) iii. (1870); also Heine (1874), 'Ueber die constante electrische Strömung in ebenen Platten,' *Borch.* lxxix. p. 1, and *Berl. Monats.* (1874) p. 186.

[3] 'On plane vortex motion,' *Quart. Jour.* xv. p. 10; also 'Solution by means of elliptic functions of some problems in the conduction of electricity and heat in plane figures. *Ibid.* xvii. p. 284.

[4] 'On some cases of fluid motion,' *Camb. Phil. Trans.* viii. p. 105 (1843).

[5] 'On the displacement in a case of fluid motion,' *Proc. Math. Soc.* iii. p. 82 (1870).

[6] 'On the irregular flight of a tennis ball,' *Mess. Math.* vii. p. 14 (1877). By some oversight the circle is made to move in the wrong direction.

[7] 'Notes on hydrodynamics,' *Mess. Math.* ix. p. 113.

[8] 'On some cases,' &c.

initial motion, when one circle has a motion of translation. He shows that in this case, which serves very approximately to determine the small vibration under gravity of the inner circle, the mass of the equivalent solid is $(b^2 + a^2)/(b^2 - a^2)$ times the mass of the fluid displaced; a, b being the radii of the circles. I[1] have discussed the most general motion of two circles, either internal, or external to one another, treating the two cases separately where the circles touch or not. The velocity and potential functions are given for any motion of the two circles, and the following particular cases are considered more in detail: (α) the motion of a pendulum inside a circular case, (β) of a circle in fluid bounded by a straight line, (γ) of two circles rigidly connected, (δ) the motion of one when the other is fixed, and lastly (ϵ) some properties of the general motion of two free circles, in all cases without cyclic motion. It may be interesting to give some of the results, which admit of quantitative determination in finite terms. If (as in β) a circle be projected from contact with the boundary line, in a direction perpendicular to it, the limiting velocity as it moves off to an infinite distance is increased in the ratio $(\frac{1}{3}\pi^2 + \rho - 1)^{\frac{1}{2}}(\rho + 1)^{-\frac{1}{2}}$. If it be projected from any point, the future path will have its concavity turned towards the plane, and will turn round and meet the plane or not, according as the direction of projection makes an angle with the perpendicular to the plane greater or less than a certain angle α, which depends only on the distance from the plane. When the circle is projected from contact, the values of α for densities of the circle 0, 1, 10 are about 41° 22′; 51° 14′; 70° 15′ respectively. If in (δ) the circles are equal, and one is projected directly from contact with the other, the limiting velocity is $(\frac{1}{4}\pi^2 + \rho - 1)^{\frac{1}{2}}(\rho + 1)^{-\frac{1}{2}}$ times the initial velocity. If it were projected in any way it will move as if attracted on the whole by the fixed circle, the path will have its concavity turned towards it, and will have two asymptotes, whose distances from the centre of the fixed circle are $(\rho + P_0)^{\frac{1}{2}}(\rho + 1)^{-\frac{1}{2}}$ times the apsidal distance, where P_0 is a certain number depending only on this distance. If, for example, they touch when nearest $P_0 = \frac{1}{4}\pi^2 - 1$. If, on the contrary, both are free to move (as in ϵ), and they are projected so that the whole 'momentum' of the system is zero, they move as if they repel one another, and the path of one relatively to the other has its convexity towards that other. If they are equal and touch one another at their nearest distance, the distance of the asymptote of the path of one from the centre of the other is $(\frac{1}{6}\pi^2 + \rho - 1)^{\frac{1}{2}}(\rho + 1)^{-\frac{1}{2}} \times$ sum of radii. If there is cyclic motion between the circles it is possible to have them moving steadily forward through the fluid, always keeping at the same distance, provided the circles are equal. The discussion[2] of this motion shows that when the radii and distance of the centres are given there are two possible relations between the velocity of translation and the relative motion, one in which they are in the same direction between the circles and the other in the opposite. If 2α be the angle between the two internal tangents to the circles, then when α is not nearly $\frac{1}{2}\pi$, the two ratios of the velocity due to cyclic motion alone, at the point half-way between the cylinders, to the velocity of translation is very approximately $2 \sec \alpha \{\pm \sqrt{(1 - \cos \alpha \sin^4 \alpha)} - 1\}$.

[1] 'On the motion of two cylinders in a fluid,' *Quart. Jour.* xvi. pp. 113 and 193, and *Proc. Camb. Phil. Soc.* iii. p. 227 (1878).

[2] 'On the condition of steady motion of two cylinders in a fluid,' *Quart. Jour.* xvii. p. 194 (1879).

When the boundary consists of two intersecting circles, the determination of the motion can be made in a manner similar to that for two non-intersecting circles. When the two circles are equal and pass through each other's centres, the velocity potential for the system moving parallel to the line of centres is $\phi = -a^2V(r^{-2} + r'^{-2})$, where r. r' are the distances of a point from the centres. This example was given before Section A at York last year by Professor A. W. Rücker.[1]

Straight Lines and Circles.—Here again our first reference must be to Stokes. In his paper 'On the critical values of the sums of periodic series' he finds the velocity potential for the fluid inside a rotating sector of a circle of angle 2α in the two forms of an infinite series and of a definite integral, and expresses in the same two forms the moment of inertia of the equivalent solid. The square of the radius of gyration is $\frac{16}{\pi a}\int_0^\infty \frac{\tanh ax}{x(x^2+4)^2}\,dx$. For special values of the angle a, the velocity potential and stream functions admit of finite expression in terms of logarithmic and circular functions. The semicircle is the simplest,[2] next comes the quadrant of a circle, and a sector of 60°, the two last given by Greenhill,[3] who has investigated the case of the sector very fully. In this paper the case when the angle is any sub-multiple of two right angles is also considered. The expressions obtained are naturally rather complicated, but they are finite and in terms of circular and logarithmic functions. For the two particular cases of the semicircle and quadrant he shows that the ratios of the squares of the radii of gyration of the equivalent solid, and the solidified fluid, are $16/\pi^2 - 1$, and $(16 \log 2)/\pi^2 - \frac{1}{3}$, respectively. He again takes up the question in a later paper[4] (1880), and obtains a finite expression for the functions when the angle of the sector is commensurable with two right angles. The square of the ratio of the radius of gyration of the equivalent solid to the radius of the circle is in this case

$$\frac{1}{\pi a}\left\{\chi\left(\tfrac{1}{2}+\tfrac{2a}{\pi}\right)-\chi(\tfrac{1}{2})\right\}-\frac{1}{\pi^2}\chi'\left(\tfrac{1}{2}+\tfrac{2a}{\pi}\right)$$

where $\chi(x) = \frac{d}{dx}\log\Gamma(x)$.

When sources and sinks exist inside a sector the motion may easily be determined by means of what is already known for the space between two lines. The position of rest of a vortex inside a sector has been determined by Lewis.[5] It lies on the line bisecting the angle at a distance from it $=\{\sqrt{(4n^2+1)} - 2n\}^{1/2n}$ times the radius, the angle of the sector being π/n. The general motion both for vortices outside and inside a circle—either for a single vortex in a sector, or symmetrical vortices, without straight boundaries, is given by Greenhill[6] with figures illustrating the paths for two, four, and six vortices respectively.

The same author has also discussed the motion in the space bounded by two concentric circles and two radii. The values of ϕ and ψ for a

[1] 'On a problem in stream lines,' *Brit. Assoc. Rep.* 1881, p. 554.

[2] 'Fluid motion in a rotating semi-circular cylinder,' *Mess. Math.* viii. p. 42 (1878).

[3] 'Fluid motion in a rotating quadrantal cylinder,' *Mess. Math.* viii. p. 89 (1877).

[4] 'On the motion of a frictionless liquid in a rotating sector,' *Mess. Math.* x. p. 83.

[5] 'Some cases of vortex motion,' *Mess. Math.* ix. p. 93 (1879).

[6] 'Plane vortex motion,' *Quart. Jour.* xv. p. 10 (1877).

rotating rectangle are given in infinite series.[1] The path of a vortex inside such a rectangle[2] admits of a very elegant expression by means of elliptic functions; as well as the ϕ and ψ for sources and sinks at the corners.[3] For instance, for a source and a sink at two adjacent corners on the same radius $\phi + \psi i = \log \operatorname{sn} \frac{n\mathrm{K}}{\pi}\left(\theta + i \log \frac{a}{r}\right)$ with analogous expressions in *cn* and *dn* for the other corners. Here the value of q is $(a/b)^n$. The position of rest of a single vortex is at a distance from the centre equal to the geometrical mean of the radii.[4] The solution for sources is also given by Allen.[5]

Ellipse (axes a, b; $a > b$). If the elliptic cylinder be considered as the limiting case of an ellipsoid when one axis becomes indefinitely large, Green may be regarded as the first worker in this field (1833); but the first to consider definitely the ellipse was Stokes (1843) in his before-mentioned paper 'On some cases of fluid motion'; but in this he only considered the motion approximately, in the space outside an ellipse of small eccentricity, for translation and rotation. He[6] has also shown that confocal conics are possible forms for stream lines, though the motion is only irrotational in the case of the rectangular hyperbola. In 1873 Beltrami[7] gave the velocity potential for the motion of an elliptic cylinder as a case of the ellipsoid, whilst Ferrers[8] determined the stream function two years later (1875) for motions of translation and rotation. In the latter year also Lamb[9] published the expressions for ϕ and ψ in the forms which are now generally used, and given in Kirchhoff's 'Vorlesungen' and Lamb's 'Theory of Motion.' In this paper will be found diagrams of the lines of flow. The path and motion of an ellipse moving in an infinite fluid have been worked out by Greenhill,[10] who has given figures illustrating the motion for the three cases when it is projected, so as to make (1) oscillations, (2) whole revolutions, and (3) when it is projected in the direction of the major axis with infinitely small angular displacement.

The same author[11] has also investigated the motion of an ellipse whose centre is fixed in a stream. In this case the time of a small oscillation is $2\pi \sqrt{\{\frac{1}{2}\sigma ab(a^2+b^2)/(a^2-b^2)\mathrm{V}^2\}}$. Problems connected with two confocal ellipses are also considered, and the initial motions of the inner, due to any sudden motions impressed on the outer, are found.

Coates[12] has worked out the values of ψ for a vortex outside and

[1] 'Fluid motion in a rotating rectangle, formed by two concentric circular arcs and two radii,' *Mess. Math.* ix. p. 35 (1879).

[2] 'Solution by means of elliptic functions of some problems in the conduction of electricity and heat in plane figures,' *Quart. Jour.* xvii. p. 284 (1881).

[3] *Ibid.*

[4] 'Plane vortex motion,' *Quart. Jour.* xv. p. 10 (1877).

[5] 'On some problems in the conduction of electricity,' *Quart. Jour.* xvii. p. 65; also *Brit. Assoc. Rep.* (1879) p. 261.

[6] 'On the steady motion of incompressible fluids,' *Camb. Phil. Trans.* vii. p. 439, and Reprint, vol. i. p. 10.

[7] 'Sui principii fondamentali dell'idrodinamica razionale,' *Mem. di Bologna*, iii.

[8] 'On the motion of a mass of water about a moving cylinder,' *Quart. Jour.* xiii. p. 115.

[9] 'Some hydrodynamical solutions,' *Quart. Jour.* xiv. p. 40.

[10] 'Notes on Hydrodynamics,' ii. *Mess. Math.* ix. p. 117 (1880).

[11] 'Fluid motion between confocal elliptic cylinders, &c.,' *Quart. Jour.* xvi. p. 227 (1879).

[12] 'Vortex motion n and about elliptic cylinders,' *Quart. Jour.* xv. p. 356, and xvi. p. 81 (1878.)

inside an ellipse, and inside a semi-ellipse, by the elliptic transformation from the solutions for the circle obtained by Greenhill.

The images inside an ellipse due to either a source, or a doublet outside it, have been determined by the writer.[1] In general it may be taken to consist of a line distribution of sources and doublets along the straight line joining the foci, and of an isolated image or not, according to the position of the original source. When this lies beyond a certain confocal ellipse, determined by the size of the bounding ellipse, there is no isolated image, whereas, if it lies within, there is an isolated image lying on the confocal hyperbola through the 'object.'

Where the ellipse degenerates into the line joining the foci the isolated image is always absent, and there is only a distribution of doublets along the line. The densities at a point are given throughout in terms of the position of the point and of the object source or doublet; these expressions for certain particular positions of the source become very simple. Thus, in the case of a line AB, and a doublet at P_1, on AB produced, and perpendicular to it, the line doublet density at a point P on the line is proportional to

$$\frac{1}{PP_1}\sqrt{\left(\frac{AP\ .\ BP}{AP_1\ .\ BP_1}\right)}.$$

The motion of a mass of fluid in the form of an elliptic cylinder rotating about its axis under the attraction of its own mass has been touched upon by Dirichlet and Riemann in their investigations on the similar problem for the ellipsoid referred to below. More particularly, Lipschitz[2] gives equations for the motion of such an ellipse, both for vibrations of form and rotation, and shows that they are purely periodic between definite limits. Kirchhoff[3] has given a simple case, where the boundary rotates without change of form—a case which is embraced in a more general solution of the same problem given by Greenhill.[4] The latter considers the motion to be generated by supposing the fluid to rotate within a rigid boundary as a solid body with angular velocity ω, and an additional angular velocity ω' to be impressed on the boundary. He finds that we may suppose the boundary removed, provided the relation between these quantities and the axes is given by

$$(\omega + \omega')^2 + \frac{4a^2b^2}{(a^2+b^2)^2}\omega'^2 = \frac{4\pi\rho ab}{a^2+b^2}.$$

The paths of the particles are in general pericycloids, which, (1) when $\omega' = \omega(a^2 - b^2)/(a^2+b^2)$ are epicycloids, (2) when $\omega + \omega' = o$, or boundary at rest, are ellipses (Stokes's case referred to above, p. 8), (3) when $\omega = o$ are circles, and (4) when $\omega' = -\omega(a \pm b)^2/(a^2 + b^2)$ are circles, which last is Kirchhoff's case.

Other Curves.—Any number of possible fluid motions can be determined by taking any solution of the equation $\nabla^2\phi = o$, and determining the stream lines, any one of which may serve as a boundary. But this

[1] 'On functional images in ellipses,' *Quart. Jour.* xvii. p. 327 (1881.)

[2] 'Reduction der Bewegung eines flüssigen homogenen Ellipsoids auf das Variationsproblem eines einfachen Integrals, und Bestimmung der Bewegung für den Grenzfall eines unendlichen elliptischen Cylinders,' *Borch.* lxxviii. p. 245 (1874).

[3] 'Vorlesungen,' &c. p. 262. *Aufl.* ii.

[4] 'On the rotation of a liquid ellipsoid about its mean axis,' *Proc. Camb. Phil. Soc.* iii. p. 233.

method, as a rule, does not afford useful results, as the curves are in general too complicated. The mathematical interest attaches itself to solutions for the case of given boundaries or given conditions, and reduces itself often to a suitable transformation by conjugate functions, whereby the given boundary may be transformed to one consisting of lines or circles, the solution of which is known. This has been applied in some of the preceding examples. Of direct solutions other than those already mentioned two require notice here. One by Ferrers,[1] who has determined the ϕ and ψ functions for the spaces (1) inside an ellipse and between the two branches of a confocal hyperbola, and (2) between an ellipse and one branch of a confocal hyperbola, when the boundary rotates; also for two confocal parabolas, the limiting case of (2). The functions are given in infinite series. The other is by Greenhill.[2] He has investigated expressions for the ϕ and ψ, due to a source, a doublet, or a vortex, in the space bounded by Cartesians, in terms of the conjugate functions given by $x + iy = \text{sn}^2\frac{1}{2}(\xi + i\eta)$, in which ξ,η give the confocal Cartesians, whose vectorial equations are $r' - r\text{dn}\xi = \text{cn}\xi$ and $r' + r\text{dn}i\eta = \text{cn}i\eta$, the foci being at the points $x = o,\ 1,\ 1/k^2$ and $y = o$.

Non-plane Two-dimensional Motion.—The hydrodynamical interest of plane two-dimensional motion consists in its physical application to the motion of cylinders in an infinite fluid, or of cylinders of finite length in the space between two planes perpendicular to and touching the ends of the cylinder. When the space considered is not plane, the motion may be represented physically by the steady motion of electricity, the surface being supposed a conductor. The surface of a sphere is one which has received some attention. The case of the motion for a source and sink at opposite extremities of a diameter was discussed by Robertson Smith[3] in his paper referred to above. Beltrami[4] has given the general solution of the equation of continuity for the surface of a sphere which is analogous to that for plane space in terms of polar co-ordinates. He shows that, θ and ϕ being the co-latitude and longitude of a point, the general solution for the potential is in the form

$$\left(\text{A}\log\tan\frac{\theta}{2} + \text{B}\right)(a\phi + b) + \Sigma\left(\text{A}_n\tan^n\frac{\theta}{2} + \text{B}_n\cot^n\frac{\theta}{2}\right)\cos(n\phi + a).$$

This he applies to the case of the motion of a spherical cap on the sphere, and finds that, a being the spherical radius of the cap and $(\theta_0 \,.\, \frac{1}{2}\pi)$ the co-ordinates of the instantaneous centre of rotation, the potential is proportional to $\sin\theta_0(\sin\frac{1}{2}a)^2\cot\frac{1}{2}\theta\cos\phi$, the centre of the cap being at the pole. The lines of flow are given by $\cot\frac{1}{2}\theta\sin\phi = \text{const.}$, and of flow relative to the cap by $(\cos a - \cos\theta)\cot\frac{1}{2}\theta\sin\phi + \cot\theta_0\cos\theta = \text{const.}$ These are the intersections with the sphere of hyperbolic cylinders whose asymptotic planes are, one parallel to the boundary of the cap (a small circle of the sphere), and the other to the great circle of the sphere which gives the instantaneous direction of motion of the centre of the cap. He also discusses the time a particle takes to describe its path, and particular forms of the paths. The ϕ and ψ functions for sources and sinks on a sphere, or certain portions of spheres, bounded by circles, have

[1] 'On the motion of water contained in certain cylindrical vessels,' *Quart. Jour.* xvii. p. 227 (1880).

[2] 'On functional images in Cartesians,' *Quart. Jour.* xviii. p. 231, 346 (1882).

[3] 'On the flow of electricity, &c.' *Proc. Roy. Soc. Edin.* vii. p. 79 (1870).

[4] 'Intorno ad un caso di moto a due co-ordinate.' *Rendiconti d. reale. Ist. Lomb.* (II.) xi. p. 199 (1878).

been investigated by Hill,[1] who arrives at the necessary expressions by transforming the variables so as to make the equation of continuity of the same form as in plane motion, and taking similar functions of those variables. Amongst many interesting results may be mentioned those for equal source and sink. Here the stream lines are the small circles through the source and sink (intersections of sphere with planes through the chord joining the points), and the potential lines are the system of small circles orthogonal to the foregoing (the intersections with planes passing through the line of intersection of the tangents to the sphere at the source and sink). Allen[2] has made a valuable remark, that the transformation which Hill has used is geometrically equivalent to transforming the equipotential and stream lines for any motion on a plane by a stereographical projection into a corresponding motion on the sphere. This might be regarded as making the theory for the spherical surface as complete as for the plane, were it not that the projections do not always correspond in simplicity to the original curves. For instance, he shows that confocal conics project into quartic curves, and that confocal sphero-conics are the projections of quartic curves. The case of motion on the surface of a cylinder is also touched upon, as it has also been by Boltzmann.[3]

b. Motion in three dimensions.

Planes.—The image of a source in presence of an infinite plane has long been known, and is obvious. Stokes was, I believe, the first to employ it. The velocity-potential for a source between two parallel planes—which is the sum of the same functions for the infinite train of images—has been given by myself,[4] whilst Greenhill[5] has solved the corresponding problem for the case of a rectangular box. When the origin is at one corner and a single source at the point $x_1.y_1.z_1$, the potential is

$$\phi = \frac{\pi}{8abc}\int_0^\infty \left\{ \theta_3\left(\pi\frac{x-x_1}{2a}, e^{-\frac{\pi^2 t}{4a^2}}\right) + \theta_3\left(\pi\frac{x+x_1}{2a}, e^{-\frac{\pi^2 t}{4a^2}}\right) \right\} dt$$
$$+ \text{ similar terms in } y_1, z_1.$$

In any actual case this has to be combined with an equal sink at some other point; it gives the power of solving the general problem of any motion of the sides, and has been used by Kirchhoff to determine the electrical resistance of a conducting parallelepipedon.

The Sphere.—The velocity-potential for the sphere was first found by Poisson[6] in 1831, in discussing the effect of the air on the motion of a ball-pendulum in it. If the elasticity of the air be neglected we get the

[1] 'The steady motion of electricity in spherical current sheets,' *Quart. Jour.* xvi. p. 306 (1879).

[2] 'On some problems in the conduction of electricity,' *Quart. Jour.* xvii. p. 65 (1880).

[3] 'Bewegung der Electricität auf einer cylindrischen Fläche,' *Wien. Sitzber.* lii. (2) p. 220.

[4] 'On velocity and electric potentials between parallel planes,' *Quart. Jour.* xv. p. 293 (1878).

[5] 'On Green's functions for a rectangular parallelepiped,' *Proc. Camb. Phil. Soc.* iii. p. 289.

[6] 'Mémoire sur les mouvements simultanés d'un pendule et de l'air environnant. *Mém. de l'Acad. d. Sc. Paris*, xi. p. 521 (1832).

case of a liquid, and he showed that the effect of an incompressible fluid is to increase the inertia of the sphere by one-half the mass of the fluid displaced by the sphere. His investigation was published in 1832, and, the year after, Green read a paper on the same subject before the Royal Society of Edinburgh, in which he considered the ball of the pendulum to be ellipsoidal. His investigation was carried out without a knowledge of Poisson's work, but he gives the same result as to the effect of the surrounding fluid. In 1835 Plana [1] also took up the subject in a long paper of 166 pages, in which he attempted to take account of the friction, and of small differences from the spherical form of the pendulum. He considered the friction on the spherical surface to be proportional to the relative motion of the fluid over the surface, and that this relative motion was the same as if there were no friction. For frictionless fluid his results agree with Poisson's, as do Stokes',[2] deduced in 1843 as a special case of a more general one.

In 1852 the same problem was solved by Dirichlet [3] independently. He found, in addition, the equation to the stream lines. The chief importance of this paper lies in the impulse it gave in Germany to the study of hydrodynamics, forming as it does the first of a series of important papers by himself, Clebsch, Riemann, Helmholtz, and Kirchhoff. Clebsch [4] (1856) also gives the stream lines as a particular case of those for the ellipsoid, and discusses with more detail the motion of a spherical ball-pendulum. Amongst new results may be mentioned the equations to the paths of particles, the co-ordinates being expressed very elegantly in terms of elliptic functions of one arbitrary parameter. The motion of a sphere in fluid when its centre of gravity is eccentric is the subject of a paper by G. J. Michaelis.[5]

It is well known how Thomson discovered that the electrification induced on a sphere by a quantity of electricity at a point outside it, produces the same effect on an external point as another portion of electricity at the optical image of the first, and how from this he developed his theory of electric images. This theory suggested to Stokes to search for an analogous theorem in fluid motion, and he found [6] that a doublet (μ) outside a sphere, with its axis directed to the centre of the sphere, has an image also at the inverse point, whose magnitude is $-\mu a^3/r^3$, where a is the radius of the sphere and r the distance of the external doublet from the centre. The importance of this lies in the fact that the motion of a sphere produces the same motion in the fluid as a doublet at its centre, and thus it gives the means of solving the case of two spheres moving along the line joining their centres. The general case, of which the preceding is a particular instance, for the image of a source of fluid

[1] 'Mémoire sur le mouvement d'un pendule dans un milieu résistant,' *Mem. d. r. Acc. di Sc. Turin*, xxxviii. p. 209.

[2] On some cases, &c., see below.

[3] *Monatsber. d. berl. Akad.* 1852.

It is curious how, even down to the present moment, Dirichlet is regarded on the Continent as the first investigator in this region, and how the work of Green and Stokes is ignored.

[4] 'Ueber die Bewegung eines Ellipsoids in einer tropfbaren Flüssigkeit,' *Crelle*, lii. p. 103 (1856).

[5] 'Over eenige gevallen van beweging in eene onsamendrukbare vloeislof,' *Nieew. Arch.* iii. p. 163.

[6] *Brit. Ass. Rep.* 1847, ii. p. 6. 'On the resistance of a fluid to two oscillating spheres.' *Reprint*, vol. i. p. 230.

outside a sphere has been given by myself[1] (1879), and may be thus stated. If a source, of strength m, is placed at a distance r, from the centre of a sphere of radius a, the 'image' consists of (1) a source at the optical image of m, and of magnitude ma/r; and (2) a constant line-sink extending from this isolated image to the centre, and of line-density, m/a. The image of a doublet (μ) with its axis in any direction is then easily deduced by making a source and sink approach indefinitely near to one another. When the axis points towards the centre, it is clear that the line-distribution disappears, and we get the result found by Stokes; when the axis is perpendicular to the line joining it to the centre, the image consists of an isolated doublet $= \mu a^3/r^3$ at the inverse point, and a line doublet thence to the centre, whose line-density at a distance ρ is $-\mu\rho/ar$. It is curious[2] that if there is a source at a point P and a constant line-sink between P and Q, where Q is a point on the line from P to the centre, then, provided the whole amount of the line-sink is equal to the amount of the source, the 'image' of this arrangement is an arrangement of the same form—viz., a source at P′ the inverse of P, and a constant line-sink between P′ and Q′, the inverse of Q, the whole amount of the line-sink being equal to that of the source at P′. This is of importance in the treatment of the motion of two spheres, when one at least changes its volume.

The image of another kind of singular point, that of the element of a vortex filament, has been determined by Lewis.[3] In this case the image of a small element of a vortex line is the optical image of the element, and their strengths are inversely proportional to the square roots of their distances from the centre. Hence, any complete vortex filament has a complete image, provided it lies on a concentric sphere. By means of this theorem Lewis has investigated the motion of a circular vortex filament inside a sphere when it moves symmetrically with respect to a diameter. When it occupies a position of rest, its radius (r) is given by $(a^2 - r^2) \log \{3\pi r^3(a^2 - r^2)^2/2a^4b^3\} = 4a^2$; where a is the radius of the sphere, and b is the radius of the sphere whose volume is equal to that of the filament.

The motion standing next in simplicity is that of the initial motion of the fluid contained between two concentric spheres when the inner begins to move. This forms one of the examples considered by Stokes[4] in his paper 'On some cases of fluid motion' (1843). He first finds the velocity potential for any motion of the bounding surfaces, and shows that if the inner sphere performs a small oscillation within the outer as a fixed boundary, the motion is the same as if the inertia be supposed increased by a mass equal to $\frac{1}{2}(b^3 + 2a^3)/(b^3 - a^3)$ times the mass of the fluid displaced, where a, b denote the radii of the inner and outer spheres respectively. He then passes on to the case where a sphere moves in fluid bounded by an infinite plane. This is important as the first application in hydrodynamics of the principle of successive 'reflection' of motion. Taking first the motion of the sphere perpendicular to the plane, he finds the normal motion at points of the plane due to the motion of the sphere on the

[1] 'On the motion of two spheres in a fluid,' *Trans. Roy. Soc.* part ii. (1880), p. 455.

[2] 'On the problem of two pulsating spheres in a fluid,' *Proc. Camb. Phil. Soc.* iii. p. 276.

[3] 'On the images of vortices in a spherical vessel,' *Quart. Jour.* xvi. p. 338 (1879).

[4] *Trans. Camb. Phil. Soc.* viii. 105.

supposition that the plane does not exist, and then adds the motion obtained by impressing on every point of the plane velocities equal and opposite to those at the same point produced by the motion of the sphere, and again, takes account of the 'reflected' motion of this from the surface of the sphere. If the fourth powers of the ratio of the radius to the distance from the plane be neglected he found that the mass of the equivalent solid is $\frac{1}{2}(1 + 3a^3/8h^3)$ times the mass of fluid displaced. When the sphere moves parallel to the plane, the problem is treated by supposing the plane removed, and an equal sphere to move as the optical image of the first. Here under the same circumstances the mass of the equivalent solid is $\frac{1}{2}(1 + 3a^3/16h^3)$ times the mass of the fluid displaced. In both cases h denotes the distance of the centre from the plane. His discovery of the image of a doublet whose axis goes through the centre of the sphere enabled him to solve further problems[1] which, however, he did not publish at the time. One of them is printed in the first volume of his collected works and is referred to below. The fact that a sphere projected from the bounding plane moves as if accelerated, whilst if it is projected parallel to the plane it moves as if attracted to it, was deduced from general reasoning in Thomson and Tait's 'Natural Philosophy,' published in 1866.

The whole question of the general motion of two or more spheres has been considered very fully by Bjerknes in a series of papers dating from 1868 onwards. In his first paper[2] he treats of the movement of two spheres moving in their line of centres, and shows how a series for the velocity-potential may be obtained. He investigates more particularly the case when their distances are so great that inverse powers of the distance greater than the seventh may be neglected, and shows that the uniform motion of one sphere, along the line of centres produces an apparent repulsive force towards the centre of the other: also the general movement of several spheres whose distances from each are so large compared with their radii, that inverse powers of this ratio greater than the fourth can be neglected. Under these circumstances the action between any two spheres is independent of the presence of the others. Forces occur depending on the acceleration and the kinetic energy of the spheres, that due to acceleration varying inversely as the third power of the distance, whilst that due to the square of the velocity depends on the inverse fourth power.

In 1871 Guthrie[3] published a curious theorem, due to Thomson. Thomson found that if two spheres are in fluid and oscillating along the line joining their centres, then, if the density of one of the spheres is less

[1] In the introduction to his paper on 'The internal friction of fluids on the motion of Pendulums' (*Trans. Camb. Phil. Soc.* ix. 1850), he says, speaking of this discovery: 'It enabled me to calculate the resistance to a sphere oscillating in presence of a fixed sphere or within a spherical envelope, or the resistance to a pair of spheres either in contact, or connected by a narrow rod, the direction of oscillation being, in all these cases, that of the line joining the centres of the spheres. . . . The method even applies, as Professor Thomson pointed out to me, to the uncouth solid bounded by the exterior segments of two intersecting spheres, provided the exterior angle of intersection be a submultiple of two right angles.'

[2] 'Om den samtidige Bevaelgelse af kugleformige Legemer i et inkompressibelt Fluidum.'—*Forhand. Skand. Naturfors.* Christiania (1868).

[3] 'On approach caused by Vibration,' *Phil. Mag.* xli. (4) p. 423. There is clearly a printer's error in the result. In the formula the fifth root occurs; in the numerical example the third root. I have ventured in the text to substitute the correct value, viz. the fourth. This paper of Guthrie's contains experiments on the action between bodies moving in fluids and also references to the work of others. For further notices see below.

than that of the fluid it is repelled or attracted according as the ratio of its radius to the distance between the centres is less or greater than $1 - \sqrt[4]{\{\frac{1}{3}(1+2\rho)\}}$. In the same year also, Bjerknes[1] extended his former investigations by taking into consideration changes of volume. The velocity-potential is obtained in an infinite series in which the terms are multiple integrals, which are integrable when the spheres move along the line of centres. This was followed by a series of papers[2] in 1875 and 1876, in which the consequences of the motion were developed more fully. If inverse powers of the distance above the fourth be neglected, the vibrations of one sphere produce only oscillations of the other, if that other does not also vibrate. Simultaneous vibrations of the same period produce mean forces of the second, third, and fourth powers of the inverse distance; thus, two spheres with concordant pulsations attract proportionally to the inverse square of the distance, and repel according to the same law, if they are in opposite phases. If a, b be the radii of the spheres then the force on (b) due to pulsations of (a) is $\frac{2\pi b^2}{r^2}\frac{d}{dt}\left(a^2 b\frac{da}{dt}\right)$ the density of the fluid being unity. Two oscillating spheres behave in the opposite manner to two magnetic poles. These actions have suggested to Herr Bjerknes analogies with electricity and magnetism, which he has illustrated by a series of beautiful and striking experiments.[3] It must be remembered,

[1] 'Sur le mouvement simultané des corps sphériques variables dans un fluide indéfini et incompressible,' *Forh. Vidensk.* Christiania, 1871.

[2] 'Forelöbige Meddelelser om de Kräfter der opstaa, naar kugleformige Legemer idet de udföre Dilatations; og Kontraktions Svingninger beväge sig i et inkompressibelt Fluidum.—*Forh. Vidensk.* p. 386, Christiania, 1875.

For an abstract and description of this, see Koenigsberger's *Repertorium für reine und angewandte Math.* i. p. 264. 'Ueber die Druck-Kräfte, die durch gleichzeitige mit Contractionen und Dilatationen verbundene Bewegungen von mehreren kugelförmigen, in einer incompressiblen Flüssigkeit befindlichen, Körpern entstehen.'—*Gött. Nach.* 1876, p. 245.

[3] For descriptions of these, see 'Versuche über die scheinbare Anziehung und Abstossung zwischen Körpern welche sich in Wasser bewegen.' Von Schiötz und Bjerknes, *Gött. Nach.* 1877, p. 291.

'Hydroélectricité et hydromagnétisme, résultats analytiques,' *C. R.* 1879.

'Do. résultats expérimentaux,' *Ib.* 1879.

'Expériences hydrodynamiques avec des corps vibrants et imitation dans un sens inverse des forces de l'électricité statique et du magnétisme,' *C. R.* 1879.

'Phénomènes dits hydroélectriques et hydromagnétiques, théorèmes fondamentaux et leur vérification expérimentale,' *Séances Soc. Phys. Paris* (1877), *Jour. Phys.* March, 1880.

'Hydrodynamiske analogier til de statisk elektriske og de magnetiske Kräfter,' *Naturen* (Christiania) 1880. Also *Forh. Sk. N.* (Stockolm).

'Sur l'imitation par voie hydrodynamique des actions électriques et magnétiques,' *C. R.* 1881.

On the same or analogous questions see also Hydrodynamic analogies to electricity and magnetism by G. Forbes, *Nature*, xxiv. p. 360 (1881). This is a description of Bjerknes' experiments.

'Phénomènes hydrodynamiques inversement analogues à ceux de l'électricité et du magnétisme.'—*Comptes Rendus*, par M. Bertin, *Ann. de Chimie et de Phys.* (5) xxv. p. 257, 1882.' This is a systematic description of Herr Bjerknes' work.

'Expériences hydrodynamiques, imitation par les courants liquides, des phénomènes electromagnétiques et d'induction.' Decharme, *C. R.* xciv. p. 440, and p. 527. 'Do. des actions des courants électriques les uns sur les autres,' p. 643. 'Do. des anneaux de Nobili, obtenus avec les courants électriques,' p. 722 (1882).

'Bäcklund: Om en särskild art af rörelse i en obegränsad, osammantrykbar vätske, i hvilken sammantrykbare kroppar äro utspridda,' *Lund. Arsskr.* xv.

Experimental Researches into the Properties and Motions of Fluids, with Theoretical Deductions therefrom by W. Ford Stanley. London, Spon, 1881.

however, that the actions are the opposite of those of electricity and magnetism—for instance, *like* oscillations attract—nor is it easy to see how the rotatory effects of magnetism can be illustrated in this manner.

In his 'Vorlesungen über mathematische Physik' (1876), Kirchhoff has given a short treatment of the question of two moving spheres, and this has been carried somewhat further by Lamb in his treatise on the motion of fluids. The present writer[1] has also applied the theory of images, referred to above, to the solution of the same problems, and has attempted[2] to sketch out an explanation of gravitation on Thomson's vortex-atom theory of matter. When two spheres intersect at an angle which is a submultiple of two right angles, the number of successive images is finite, and the velocity-potential has a finite form. Stokes,[3] in the reprint of his papers, has worked out in detail the case when two spheres cut at right angles. If r, θ; r', θ'; r_1, θ_1, be the polar co-ordinates of any point referred to the centres of the spheres, and the middle point of the common chord respectively, then the velocity-potential when they move along the line of centres is $-\frac{1}{2}\mathrm{V}\{a^3 \cos \theta/r^2 - a^3b^3 \cos \theta_1/c^3r_1{}^2 + b^3 \cos \theta'/r'^2\}$, c being the distance between the centres. In this case the mass of the equivalent solid is

$$\tfrac{1}{3}\pi\rho c^{-3}\{4c^3(a^3+b^3)-2(a^6+b^6)-3a^2b^2(a+b)^2\}.$$

The Ellipsoid.—The solution of the problem of the most general motion of an ellipsoid in fluid is due to the successive labours of Green (1833), Clebsch (1856), and Bjerknes (1873). To the first we owe the velocity-potential for a motion of translation, to the second that for a motion of rotation and the stream-lines both for translation and rotation, whilst the third has given us the solution when the axes of the ellipsoid change in any manner with the time.

Green's[4] paper was read in 1833. In this he finds the velocity potential for translation only, and the effective momentum of the fluid. In finding the effective momentum Green neglected the term in the expression for the pressure at a point which depends on the square of the velocity, and he supposed, therefore, that his result was only true for small vibrations. It was not till ten years later, when Stokes proved that this term produces no effect on the resultant pressure on a single body in an infinite fluid, that it could be seen that Green's value of this momentum was rigorously true. His solution for the sphere has already been mentioned; he also gave the analogous expressions for the spheroids. In 1835 Plana, in his before-mentioned paper, showed how to determine the velocity-potential for a surface of revolution only slightly differing from a sphere and moving parallel to its axis. Nothing more seems to have been done for twenty-three years, until Clebsch's[5] investigations were published in 1856, although the paper seems to have been finished in 1854. The first part deals with the general theory of fluid motion, and has already been referred to in the portion of this report presented to the Association last year. Here we confine ourselves to his results bearing directly on the

[1] 'On the motion of two spheres in a fluid,' *Trans. Roy. Soc.* pt. ii. p. 455 (1880).

[2] 'On the problem of two pulsating spheres in a fluid,' *Proc. Camb. Phil. Soc.* iii. p. 276, and iv. p. 29.

[3] 'On the resistance of a fluid to two oscillating spheres,' reprint, vol. i. p. 230 (1880).

[4] 'Researches on the vibration of pendulums in fluid media,' *Trans. Roy. Soc. Edin.*, vol. xiii.; also reprint, p. 315.

[5] 'Ueber die Bewegung eines Ellipsoids in einer Flüssigkeit,' *Crelle*, lii. p. 119.

ellipsoid. Clebsch was unacquainted with Green's work, and rediscovered his values of the velocity-potential for a motion of translation. In addition to the potentials for translation and rotation he gives the equations of the lines of flow for translation, in terms of ellipsoidal co-ordinates, in the form $\log y = \int_0^\lambda f(\lambda)d\lambda$, where $\lambda.\mu.\nu$ are the ellipsoidal co-ordinates of a point $(x.y.z)$, with a similar expression for $\log z$, which is so related to the former that yz may be expressed in terms of an elliptic integral of the second kind. The case of rotation is a more complicated one, and was only completed in a note[1] to this paper. Here the co-ordinates $\mu.\nu$ are expressed as integrals of functions of λ, and thus the solution is reduced to a question of quadratures. All these simplify very much when the ellipsoids are spheroids. Another period of nearly twenty years followed, until Bjerknes[2] completed the general solution by investigating the potentials when the boundary itself changes its form, yet so as to remain ellipsoidal. He considers the generalised problem of motion in space of n dimensions, and extends the former results to this case. The second paper is divided into two parts, the first devoted to the motion in the infinite fluid outside the ellipsoid, the second to that inside. His results are given below, for space of three dimensions.

As the results are important, and extremely interesting, I have thought it would be well to give a short notice of the results of the three foregoing writers, expressed in a consistent notation.

Let $E \equiv 1 - \frac{x^2}{a^2+\lambda} - \frac{y^2}{b^2+\lambda} - \frac{z^2}{c^2+\lambda}$, so that $E_0 = o$ is the equation to the boundary at any time, the axes being $a.b.c.$ Further, let D denote the product $\sqrt{\left(1+\frac{\lambda}{a^2}\right)\left(1+\frac{\lambda}{b^2}\right)\left(1+\frac{\lambda}{c^2}\right)}$. Then all the velocity-potentials can be expressed in terms of Ω where

$$\Omega = \pi \int_\lambda^\infty \frac{E}{D}\, d\lambda$$

viz., the constants A.B.C. being properly chosen, we have for translation parallel to the axis (a)

$$\phi = A\frac{d\Omega}{dx} \qquad \text{(Green)};$$

for rotation about the axis (a)

$$\phi = B\left(y\frac{d\Omega}{dz} - z\frac{d\Omega}{dy}\right) \qquad \text{(Clebsch)};$$

for variation of the axis (a)

$$\phi = C\dot{a}\frac{d\Omega}{da} \qquad \text{(Bjerknes)}.$$

In the last case, if the axes vary so as to keep the volume constant, then the sum of the C must vanish, whereas if they vary so that the

[1] *Crelle*, liii. p. 287.

[2] 'Verallgemeinerung des Problems von dem ruhenden Ellipsoid, in einer bewegten unendlichen Flüssigkeit,' *Gött. Nach.* (1873) p. 448. 'Verallgemeinerung des Problems von den Bewegungen welche in einer ruhenden, unelastischen Flüssigkeit die Bewegung eines Ellipsoids hervorbringt,' *Ibid.* p. 829.

ellipsoid always remains similar to itself, the potential takes the very simple form of

$$\phi = -\tfrac{1}{2}\frac{\dot{a}}{a}\int_\lambda^\infty \frac{d\lambda}{\mathrm{D}}$$

The effective mass and the effective moment of inertia have been given by Green and Clebsch respectively in not very complicated forms, but it does not seem worth while to reproduce them here. The function Ω also serves to determine the stream-lines for a spheroid moving parallel to its axis. They are given by Kirchhoff in his 'Vorlesungen' in the form $\left\{ \mathrm{C}\frac{d\Omega}{d\rho} + \tfrac{1}{2}\rho \right\} = \text{const}$, $(\rho . x)$ being the cylindrical co-ordinates of any point, and the other equation being given by any plane through the axis.

When the space in question is that inside an ellipsoid, the functions become extremely simple. For translation the velocity is, of course, a linear function of the rectangular co-ordinates, whilst for rotation about the axis (a) the velocity-potential is given by $\phi = \omega\frac{b^2 - c^2}{b^2 + c^2}yz$. When the axes change, the fluid being incompressible, the volume must remain unaltered, or $\dot{a}/a + \dot{b}/b + \dot{c}/c = o$. For this motion Bjerknes has shown that

$$\phi = \tfrac{1}{2}\left(\frac{\dot{a}}{a}x^2 + \frac{\dot{b}}{b}y^2 + \frac{\dot{c}}{c}z^2\right).$$

He has also shown that if we suppose the density to change with the time alone, yet so as to preserve the same mass of fluid within the ellipsoid, we may dispense with the condition $\Sigma\,\dot{a}/a = o$. If now $\mathrm{E} = 1 - \frac{x_1^2}{a_1^2} - \frac{x_2^2}{a_2^2} \ldots$ and $\mathrm{D}^2 = \Pi\left(1 + \frac{\lambda}{a_1^2}\right)$, all the above results still hold for n variables.

I have not been able to discover who first determined the potential for the internal motion when the boundary rotates. It was given by Bjerknes,[1] Beltrami,[2] and Clerk Maxwell,[3] all in 1873, but I believe the results must have been known before. Maxwell set it in a fellowship examination at Trinity College, Cambridge, with a rider, that after a certain number of revolutions, all the liquid particles would occupy the same positions relatively to the boundary.

Several other writers have discussed the motion of the ellipsoid, but their work has either been based on that of Green or Clebsch, or their results have been developed anew. A short notice, in order of the several papers, will therefore suffice here. Ferrers[4] (1875) deduces the velocity-potential for translation and rotation, and finds the *vis viva* of the fluid motion by showing that the velocity-potential for a point just outside the surface, bears a constant ratio to that just inside. This is a valuable remark, and shortens the calculation very much, for since the normal motion is the same in both cases, it follows that the energy of the motion outside has the same ratio to that within. It is seen at once how this enables us to deduce immediately the energy for translation. Sharpe[5] (1876)

[1] See above. [2] *Sui Principii, &c.*, § 26. *Mem. di Bologna*, iii.

[3] The question is given in the last edition of Besant's Hydromechanics amongst the examples.

[4] 'On the motion of an infinite mass of water about a moving ellipsoid,' *Quart. Jour.* xiii. p. 330.

[5] 'On fluid motion,' *Mess. Math.* v. p. 125.

uses the methods of Green developed in his memoir on the determination of the attractions of ellipsoids of variable densities, to obtain the velocity-potentials for translation and rotation, but he does not refer to Green's memoir on the same subject. In 1879 Greenhill[1] discussed the motion of an ellipsoid in general, and in particular of a spheroid. Amongst the results obtained may be mentioned the condition that a prolate spheroid projected through a fluid may keep its point in front. He found that it must have an angular velocity about the axis

$$> 2\surd\{c_{33}c_{44}(1 - c_{33}/c_{11})\}/c_{66}$$

where c_{11}, c_{33} are the effective masses along and perpendicular to the axis, and c_{66}, c_{44} the effective momenta of inertia about the axis, and a line perpendicular to it.[2] In this same paper he has determined the initial motion of an ellipsoïdal solid within a confocal ellipsoidal shell, when the shell has any motion of translation or rotation impressed on it, also the small oscillations of such a body about the position of confocality. In the same year also Craig[3] published a paper dealing with the same questions with reference to a single ellipsoid, and containing transformations to the notation of elliptic functions.

By making one of the axes of an ellipsoid indefinitely small we arrive at a solution of the equation of continuity with conditions over a plane elliptic disc, but which does not satisfy the hydrodynamic conditions that the pressure must be everywhere finite. The solution of the discontinuous motion which ensues when a disc is moved perpendicular to itself through a perfect fluid has yet to be found.

Another motion in connection with surfaces of the second degree is that where the stream-lines are the lines of curvature on a family of one kind of confocal quadrics—or are the intersections of two families and orthogonal to the third. By supposing the hyperboloid of one sheet to degrade into the space outside the focal ellipse we get the solution of the equation of continuity for fluid flowing through an elliptic hole in a plane.

Fluid Ellipsoid and Sphere under their own Attractions.—The problem of the ellipsoidal forms of equilibrium of a rotating fluid, under the attraction of its own particles, is naturally the next object for consideration. Since Maclaurin's discovery of the spheroidal form of equilibrium, and Laplace's discussion of it, little seems to have been done until Jacobi announced to the French Academy, in 1834, that particular ellipsoids, with three unequal axes, could also be forms of equilibrium for fluid rotating about the least axis. The fact being discovered, several proofs were given by different writers, Liouville,[4] Ivory,[5] Pontecoulant,[6] and others. The first to discuss the case with any fulness was C. O. Meyer,[7] of Koenigsberg, who set himself to do for Jacobi's case what Laplace had done for Maclaurin's. If ω be the angular velocity, and if the ratio of $\omega^2/2\pi$ to the force between two unit volumes of the fluid at unit distance, be

[1] 'Motion of liquid between two confocal ellipsoids,' *Quart. Jour.* xvi. p. 234.

[2] For a simpler proof of this see a paper by the same author: 'Steady motion of a top and of a solid of revolution moving in an infinite fluid,' *Quart. Jour.* xvii. p. 86 (1880).

[3] 'On the motion of an ellipsoid in fluid,' *Amer. Jour. Math.* ii. p. 260.

[4] *Journal de l'école polytechnique*, T. xiv. p. 289.

[5] *Phil. Trans.* pt. i. for 1838, p. 57.

[6] *Système du Monde*, T. ii.

[7] 'De Aequilibrii formis ellipsoidicis, *Crelle*, xxiv. p. 44.

denoted by V, then the combination of Meyer's investigation and Laplace's, gives the following results. If an ellipsoid is to be a form of equilibrium, V must lie between the values $V = 0$ and $V' = \cdot 2246 \ldots$ If V lies between 0 and $V_0 = \cdot 18711 \ldots$ then for a given value of V there is *one* ellipsoidal form with unequal axes, and *two* spheroidal forms, whilst for $V = V_0$ the former coalesces into that spheroidal form which has the less axis of rotation. When V is between V_0 and V' there can only be *two* spheroidal forms, which for $V = V'$ coalesce into one. The ultimate spheroid to which the ellipsoid approximates when $V = V_0$ has the ratio of its axes equal to $\cdot 5827 \ldots$ For $V = 0$ the limit for the ellipsoid is the circular cylinder, whilst the spheroids are—one a sphere and the other an infinite disc. It is clear that the most natural datum to take is not the angular velocity but the angular momentum, which remains constant, however the fluid may change its form. This was a point of view adopted by Laplace in treating of the spheroidal form, and Liouville[1] took up Meyer's problem in the same way in a paper read before the French Academy of Sciences in 1843, in which he showed that the ellipsoidal form with unequal axes is only possible provided the ratio of the angular momentum to the mass is greater than a certain limit, thus differing from the spheroids, which are forms of equilibrium for any given angular momentum. What happens when the angular velocity of a spheroid is too great for it to keep its form? This could be answered generally from the foregoing theories, viz., that the spheroid would become flatter, so decreasing its angular velocity, and that it would vibrate about some mean position; but whether its external form would always be spheroidal, or what the precise manner of the movement might be, could not be decided. This question was answered, and the complete theory of the motion of spheroids of fluid investigated, in a posthumous paper by Dirichlet,[2] edited and enlarged by Dedekind. The extremely beautiful, and in its fundamental idea simple, theory of Dirichlet threw open to mathematicians a new and rich field for further investigations, of which they were not slow to avail themselves, so that now it may be said that we know the general properties of the motion of a mass of fluid moving with a free ellipsoidal surface under its own attraction. Dirichlet's first conception dates from the winter of 1856–1857, so his editor, Dedekind, says; but the author, wishing to extend them further, did not publish his results in full, and they did not appear until 1859, after his death, when Dedekind published them with some further results of his own. I will first attempt to give a general idea of his method, then refer to the chief results of his investigation, and afterwards pass on to notice the work done by other mathematicians, following on the lines laid down by him.

Considering that the Lagrangrian method of treating fluid motion is better fitted than the Eulerian when the boundary surface changes with the time, he asks the question, Is it possible to have the co-ordinates of a particle at any time linear functions of its original co-ordinates, and if so, to what kind of motion does it refer? It is clear at once that those particles originally lying on an ellipsoid must always do so, though not

[1] This was published in the *Additions à la Connaissance des Temps* for 1846, and also in 1851 in *Liouville's Journal*, xvi. p. 241, under the title 'Sur les figures ellipsoïdales à trois axes inégaux, qui peuvent convenir à l'équilibre d'un masse liquide homogène, douée d'un mouvement de rotation.'

[2] 'Ueber ein Problem der Hydrodynamik,' *Abhand. kön. Ges. Wiss. Gött.* viii. p. 1, and *Borch.* lviii. p. 181.

in general the same. The coefficients of the original co-ordinates will be nine in number, and functions of the time alone. Substituting the velocities and the attractive forces in the equations of motion, it is found that the initial co-ordinates enter linearly, and hence, in order to have a free surface, the pressure must be of the form

$$P + \sigma\left(1 - \frac{x_0^2}{a^2} - \frac{y_0^2}{b^2} - \frac{z_0^2}{c^2}\right)$$

where the coefficient of σ equated to zero gives the initial surface, and σ is a function of the time alone. Equating to zero the coefficients of x_0, y_0, z_0 there result, with the equation of continuity, ten equations to determine σ and the nine coefficients. This is the fundamental idea; for the development I must refer the reader to the paper itself, contenting myself here with giving some of the chief physical results of Dirichlet's investigation. This was confined, so far as he worked it out in detail, to surfaces of revolution. When there is no rotation, and the original form is an oblate or prolate spheroid at rest, the form vibrates through the sphere to a prolate or oblate spheroid respectively, and he finds equations to determine the limits and the time of vibration. If in any position the velocity of change of an axis surpasses a certain limit the form does not vibrate, but the spheroid either lengthens infinitely or flattens infinitely, but the presence of the slightest amount of rotation prevents the former ultimate state, a result easily foreseen from the constancy of angular momentum. When rotation occurs three cases present themselves, distinguished by the relation of the angular velocity to the momentary form. The first gives no change of form, and leads to Maclaurin's spheroid; in the second the spheroid vibrates as well as rotates; and in the third it rotates and either flattens itself without limit, or, *in the reverse direction*, tends to an ultimate form not of infinite length. In the second case the motion is only possible without a uniform external pressure over the surface, provided the angular velocity at the moment of greatest lengthening is less than a certain limit. The last section of this paper is nearly all due to Dedekind. In the foregoing the same particles always form the principal axes of the ellipsoid. Dedekind states here that there are only two other cases in which this is the case, one in which an ellipsoid vibrates without rotation, for which the co-ordinates are proportionate to their initial values, and the other is Jacobi's ellipsoid. He further states another possible motion where an ellipsoid satisfying Jacobi's conditions retains its form stationary in space, with an internal motion of the particles given by

$$x = x_0 \cos kt + \frac{a}{b} y_0 \sin kt, \quad y = -x_0 \frac{b}{a} \sin kt + y_0 \cos kt, \quad z = z_0.$$

This may be referred to as Dedekind's ellipsoid.

The proof of these theorems Dedekind gave in an appendix[1] to Dirichlet's paper republished in Borchardt's Journal, and in addition a remarkable reciprocal law between two correlated motions with the same boundary surface. It is thus stated by him. To every motion of a fluid ellipsoid expressed by the equations $x = lx_0 + my_0 + nz_0$, $y = l'x_0 + m'y_0 + n'z_0$, $z = l''x_0 + m''y_0 + n''z_0$ whose original surface has the equation $\frac{x_0^2}{a^2} + \frac{y_0^2}{b^2} + \frac{z_0^2}{c^2} = 1$ corresponds, by changing the initial state of motion,

[1] 'Zusatz zu der vorstehenden Abhandlung,' *Borch.* lviii. p. 217.

a second motion of the same ellipsoid expressed by the equations

$$x = lx_0 + \frac{a}{b}l'y_0 + \frac{a}{c}l''z_0,\ y = \frac{b}{a}mx_0 + m'y_0 + \frac{b}{c}m''z_0,$$

$$z = \frac{c}{a}nx_0 + \frac{c}{b}n'y_0 + n''z_0.$$

This law of reciprocity, applied to Jacobi's case, gives Dedekind's at once.

The unknowns adopted by Dirichlet are not well adapted for considering the changes of shape and position of the fluid boundary; what is really wanted is the variation of the axes, their motion, and the motion of the fluid relative to the ellipsoidal axes at any time. Riemann,[1] taking up the problem where left by Dirichlet and Dedekind, adopted as his unknowns, σ, the axes, their instantaneous rotations about themselves, and the instantaneous rotations of a second set of axes, which give the relative motion of the fluid, and which may be defined as follows. The particles originally lying on the axes, at all future time lie on a set of conjugate axes of the momentary ellipsoid—are, in fact, the lines to which the axes are deformed by a pure strain. If the momentary ellipsoid be changed by a pure strain to a sphere these become an orthogonal system, and are the second system referred to.

Having formed the differential equations, and the integrals equivalent to constant impulsive couple, the equation of energy, and the surface integral of vortex strength, Riemann devotes his attention to considering the general question of persistence of form, where therefore the axes are constant, and for which his form of the equations is very suitable. He proves that if the form is to be persistent the axis of rotation of the fluid must lie in a principal plane of the ellipsoid, and must be fixed relatively to it. Calling $a\ b\ c$ the axes in descending order of magnitude we may state his results as follows. For the more general case where the axis of rotation lies in a principal plane there are three sub-cases; (α) axis in plane of greatest and least axis, with $a + c \leq 2b$; (β) axis also in same plane with $a - c > 2b$ and $c^2 < \dfrac{b^2(a^2 - 4b^2)}{a^2 - b^2}$; ($\gamma$) axis in plane of mean and greatest axis, with $a - b > 2c$ and

$$\int_0^\infty \frac{\lambda d\lambda}{\mathrm{D}\,(a^2 + \lambda)}\left\{\frac{4c^2 - b^2 + a^2}{b^2 + \lambda} - \frac{a^2}{c^2 + \lambda}\right\} \leqq 0.$$

where $\mathrm{D}^2 = \left(1 + \frac{\lambda}{a^2}\right)\left(1 + \frac{\lambda}{b^2}\right)\left(1 + \frac{\lambda}{c^2}\right)$. In this case there is necessary an external pressure in order to preserve the continuity of the fluid, unless a, b, c are subject to another condition. In the more special case (δ) of motion about a principal axis, this axis must be either the least or the mean. In fact calling c the axis of rotation and a the greatest axis, c must lie between $b + \alpha$ and $b - \alpha'$ where α, α' depend on the solution of a transcendental equation. If a decreases towards coincidence with b, these limits for c become b and $\cdot 303327\, b$, but if $a = b$ exactly (Maclaurin's spheroid) c can have any value between o and a. Jacobi's and Dedekind's motions belong to this case, which also serves to connect continuously cases (α) and (γ), whilst case (β) remains isolated.

Riemann gives the following way of representing the foregoing per-

[1] 'Ein Beitrag zu den Untersuchungen über die Bewegung eines flüssigen gleichartigen Ellipsoides,' *Abh. könig. Ges. Wiss. Gött. Math. Class.* ix. p. 3.

sistent motions. Suppose the particles to describe similar ellipses in parallel planes perpendicular to a principal section of the ellipsoid in the same way as if attracted to the centres of their paths. Then the actual motion may be represented by supposing the whole system to have an extra motion of uniform rotation about an axis in that principal plane. In other words we may suppose the motion set up in the same way as imagined by Greenhill, referred to below. In the latter part of his paper he shows that when the axis of rotation is not a principal axis the motion is unstable, that Jacobi's and Dedekind's ellipsoidal forms are stable, and that in the other cases the motions are not stable if the two rotations which represent the motion are in the same direction.

In the same year as Riemann's researches appeared, Brioschi[1] published a paper in which he investigated equations for the moving axes of the ellipsoid and the molecular rotations. Dedekind's reciprocal law follows also easily from his forms of the differential equations. The investigations of Dirichlet and Riemann have been co-ordinated and published in Italian by Padova[2] with some extensions of his own, when the ellipsoid changes its form periodically.

In 1879 and 1880, in the 'Proceedings' of the Cambridge Philosophical Society, Greenhill[3] took up the same problem so far as it relates to motions with persistent form, but from quite a different point of view from that of Dirichlet. Instead of the Lagrangian equations he uses the Eulerian referred to moving axes. The fluid is supposed enclosed in a rigid envelope without mass, the whole system to have a rotation as a rigid body communicated to it about one line through the centre, and then a rotation of the shell alone about another. This is quite as general as Dirichlet's, and has the advantage of expressing the motion in terms of quantities whose dynamical meanings are evident. As the velocity-potentials for the last rotations are known, the equations are obtained with the greatest ease, and it only remains to find the condition that the pressure of the fluid on the shell may be everywhere the same, in which case the shell may be removed and the fluid mass will move as before. In the first paper the case of rotation about the principal axis is alone considered, and the relations between the axes and two rotations deduced. This is case (δ) of Riemann. In the second paper he takes up the general question, and gives the condition for a free surface, but does not discuss the equation giving the condition. The calculations can be even here much simplified by considerations adduced at the end of the paper.

On the same subject reference may be made to papers by Lipschitz[4] (1874) and Hagen[5] (1879). The former uses Riemann's form of Dirichlet's expressions for the positions of the particles, finds the action, and applies Hamilton's principle. The latter does not refer to any of the

[1] 'Développements relatifs au § 3 des Recherches de Dirichlet sur un problème d'hydrodynamique,' *Borch.* lix. p. 63. 1861 (dated Nov. 1860).

[2] 'Sul moto di un ellissoide fluido ed omogeneo,' *Ann d. Sc. Norm. Pisa.* 1868–9.

[3] 'On the rotation of a liquid ellipsoid about its mean axis,' *Proc. Camb. Phil. Soc.* iii. p. 233.

'On the general motion of a liquid ellipsoid under the gravitation of its own parts,' *Proc. Camb. Phil. Soc.* iv. p. 4.

[4] 'Reduction der Bewegung eines flüssigen homogenen ellipsoids auf das Variationsproblem eines einfachen Integrals, und Bestimmung der Bewegung für den Grenzfall eines unendlichen elliptischen Cylinders,' *Borch.* lxxviii. p. 245.

[5] 'Zur Theorie der drei ellipsoidischen Gleichgewichtsfiguren frei rotirender homogener Flüssigkeiten,' *Schlöm. Zeits Math.* xxiv. p. 104.

foregoing investigations, but gives approximations when the eccentricities are very small or very large. The motion of a sphere under its own attraction when slightly deformed, according to a spherical harmonic of order n, is the subject of a paper by Thomson.[1] The time of oscillation is shown to be $2\pi\sqrt{\{(2n+1)a/2n(n-1)g\}}$, where g is the acceleration at the surface produced by the gravitation. This is independent of the size, and depends only on the density of the sphere. The forced oscillations of liquid spheres have been shortly treated by G. H. Darwin[2] in a similar manner.

All the foregoing go upon the supposition that the density throughout the mass is constant, but this is not the case with the planetary masses, at least with the earth. This led Betti[3] to take up the question of the equilibrium of heterogeneous ellipsoids, the surfaces of equal density being similar to the external surface. The investigation is not pressed to qualitative results, and is chiefly of mathematical interest.

Other Surfaces.—When the meridian curve of a surface of revolution can be expressed in the form $V = \Sigma\, c/r^3 = 1$ where the r denotes the distances of a point from each of a set of fixed points on the axis, the velocity-potential for a motion of translation parallel to the axis is easily written down. The solution is due to Hoppe,[4] and takes the simple forms $\phi = \lambda\,\{x + \frac{1}{2}\,\Sigma\, c(x-a)/r^3\}$ and $\psi = \rho^2\,(1 - V)$, in which λ is a constant, a the distance from the origin of the point from which r is measured, and ρ the distance of the variable point from the axis. He has drawn figures of the lines of flow for the particular case $81/r^3 - 16/r'^3 = 1$. Another surface of revolution is that formed when a circle rotates about a line in its own plane. An investigation of this, based on notes taken at a course of lectures delivered by Riemann, has been published by Gödecker,[5] the velocity-potential being obtained as an infinite series. The velocity-potential when the ring moves perpendicularly to its plane was given independently by myself[6] in 1881. For an infinitely small wire of any form with cyclic motion through the opening the solution flows at once from Helmholtz's theory of the vortex filament. This has been treated of by Kirchhoff[7] and Boltzmann.[8]

c. Viscous Fluid.

Motion in Tubes and Canals.—Naturally the first problem to which the equations of viscous motion were applied was that of the flow of

[1] 'Oscillations of a liquid sphere," *Phil. Trans.* 153 (1863) p. 608.

[2] 'On problems connected with the tides of a viscous spheroid,' *Phil. Trans.* Part. II. 1879, p. 585.

[3] 'Sopra i moti che conservando la figura ellissoidale a una massa fluida eterogenea,' *Annali di Matem.* (2) X. p. 173 (1881).

[4] 'Vom Widerstande der Flüssigkeiten gegen die Bewegung fester Körper,' *Pogg. Ann.* xciii. 1854. 'Determination of the motion of conoidal bodies through an incompressible fluid,' *Quart. Jour.* i. p. 301.

[5] 'Die Bewegung eines kreisförmigen Ringes in einer unendlichen incompressiblen Flüssigkeit,' *Pr. Göttingen*, 1879.

[6] 'On Toroidal Functions,' *Trans. Roy. Soc.* Part. III. 1881, p. 609.

[7] 'Ueber die Kräfte, welche zwei unendlich dünne, starre Ringe in einer Flussigkeit scheinbar auf einander ausüben können,' *Crelle*, lxxi. and Reprint, p. 404.

[8] 'Ueber die Druckkräfte, welche auf Ringe wirksam sind, die in bewegte Flüssigkeit tauchen,' *Crelle*, lxxiii. p. 111.

See Part I. of this report, p. 74.

fluids through tubes and along canals. Stokes,[1] in his first paper on viscosity, worked out the case of water flowing down an inclined circular cylinder under the action of gravity, as an example of the methods developed in the paper. In a cylinder of radius a, inclined at an angle α, the velocity at a distance r from the axis is $k(a^2 - r^2) + U$, U being the velocity at the surface, and $k = \frac{1}{4} g \sin \alpha / \mu$. In 1860 Helmholtz[2] considered the analogous question where the motion is caused by a difference of pressure at the two ends, allowing also for a certain amount of slipping at the surface of the tube. Here the velocity is given by $k(a^2 + 2\lambda a - r^2)$, where $k =$ (diff. of pressures) $/4\mu l$, which gives a flow of $\frac{1}{2}\pi k \rho (a^4 + \lambda a^3)$, agreeing well with experiments. The same question has also been treated by Stefan, Boussinesq, Butcher, Graetz, and Greenhill. Stefan[3] takes into consideration a motion of rotation of the vessel as well. Boussinesq's[4] investigations are more general than the others, and extend to tubes of non-circular sections. Considering the equation $\frac{d^2u}{dx^2} + \frac{d^2u}{dy^2} + 4k = 0$, which gives the velocity parallel to the axis, he shows, from the principle of similitude, that in tubes of similar sections the velocities at corresponding points are proportional to k and the areas of sections, and that the flows in the same times are proportional to the fourth powers of the constant of similarity—the forces acting being the same. He then solves for the particular cases where the sections of the tubes are—(1) elliptic, (2) rectangular, and (3), in a note at the end of the paper, where the section is an equilateral triangle. If A be the area of the section, the flow for the elliptic tube is $kAa^2b^2/(a^2 + b^2)$ for the triangular (sides $= 2a$) is $kAa^2/5$, whilst for the rectangular the expression is naturally more complicated. After noticing the case where in a straight tube the section gradually changes, he passes on to consider the motion where the axis of the tube is circular. This is interesting, as a steady motion in circles is impossible if the boundary is at rest. Treating the velocities in any section of the tube as small compared with the velocity across it, he solves the equation when the section is a rectangle whose height is small compared with its breadth. The motion consists of two circulations combined with a translatory motion along the tube of greater magnitude. If the rectangular section be divided by a medial line in the plane of the tube, the circulations may be represented by supposing the particles of fluid near it to move outwards, increasing their distance from it, and at last, on nearing the outer boundary, reversing their direction, and coming back nearer the longer sides. A similar result was also subsequently (1875) arrived at by Oberbeck. Boussinesq[5]

[1] 'On the theories of the internal friction of fluids in motion, &c.' *Camb. Phil. Trans.* viii. p. 287.

[2] 'Ueber die Reibung tropfbarer Flüssigkeiten,' *Sitzber. d. k. Akad. Wiss. Wien.* xl. p. 652, and *Collected Works*, Bd. I. p. 215.

[3] 'Ueber die Bewegung flüssiger Körper,' *Sitzber. d. k. Akad. Wien.* xlvi. p. 495. The dimensions of the coefficient of viscosity are wrongly given. He seems to regard the vortex rotations as if the small elements of fluid turned round as rigid bodies.

[4] 'Mémoire sur l'influence des frottements dans les mouvements réguliers des fluides,' *Liouv.* (2) xiii. p. 377 (1868).

[5] 'Essai sur la théorie des eaux courantes,' *Acad. des Sciences.* Paris. *Mém. par divers Savants*, xxiii. xxiv. 1877. This is a long memoir, consisting of 680 quarto pages of printing. The latter part is devoted to wave motion, and this contains some results of value—especially the theory of the solitary wave; but this had been published before in Liouville. (See first part of this report.)

has published further investigations on the same subject, but more from the point of view of the hydraulic engineer.

In 1876 Butcher, in his paper before referred to,[1] also touches on the question of the motion in straight tubes, but without adducing new results. Besides this he finds the general form for Stokes's stream function for a motion taking place in planes through an axis. Graetz[2] has worked out precisely the same questions as Boussinesq, to whose work he does not refer. He has taken the trouble to calculate numerical results for a tube with a square section, and has also followed out St. Venant's idea by taking algebraical solutions of the equations, and finding for what shaped tubes they are the solutions.

Greenhill[3] has made a valuable remark by which the motion of a viscous fluid in a straight tube of any section, without gliding at the surface, may be deduced at once from the solution for the case of the motion of a perfect fluid in a cylinder of the same section rotating about its axis. This is seen at once when it is noticed that the differential equation for the velocity parallel to the axis in the first case has precisely the same form as that for the stream function *relative* to the boundary, rotating with an angular velocity $2k$; and that the bounding condition for the two functions is the same, if in the first case the fluid is supposed to stick fast to the boundary. In this way the velocities in tubes whose sections are a circle, an ellipse, an equilateral triangle, two hyperbolas, a sector of a circle, and a rectangle, are written down at once.

Cylinders.—If two co-axial cylinders rotate with different velocities, ω_1, ω_2, the velocity of the fluid between at a distance r from the common axis, when steady, has been given by Stokes,[4] with a single cylinder in an infinite fluid as a particular case. When the motion takes place between two co-axial cylinders at rest—being produced and kept up by pressures across two plane sections through the axis—the expression for the velocity is not algebraical as in the previous case. The solution for this is due to Boussinesq, and is given in his paper in Liouville just referred to. Rohrs[5] treats a similar question, taking account of non-permanent motion. The determination of the motion of the fluid when a cylinder oscillates in a direction perpendicular to its axis, forms one of the chief problems considered by Stokes[6] in the second of his classical papers on viscosity. The method employed is precisely similar to that adopted for the corresponding problem for the sphere (noticed below); but, unfortunately, the solution of the differential equations occurring cannot be represented in finite forms, as in that case. The functions entering are cylindric harmonics, and this introduces a difficulty in applying the condition of finite motion at an infinite distance, to determine the arbitrary constants appearing in the solution, but that is surmounted.

[1] 'On Viscous Fluids,' *Proc. Lond. Math. Soc.* viii. p. 120. (See first part of report, p. 79.) His analysis is wrong where he considers the determination of the arbitrary constants in the solution from the bounding conditions.

[2] 'Ueber die Bewegung von Flüssigkeiten in Röhren,' *Zeits. f. Math. u. Phys.* xxv. pp. 316, 375 (1880).

[3] 'On the flow of viscous fluid in a pipe or channel,' *Proc. Lond. Math. Soc.* xiii. p. 43 (1881).

[4] 'On the friction of fluids, &c.' (1845).

[5] 'Spherical and cylindric motion in viscous fluids,' *Proc. Lond. Math. Soc.* v. p. 133 (1874).

[6] 'On the effect of the internal friction of fluids on the motion of pendulums,' *Camb. Phil. Trans.* ix. part ii. p. 35.

The results are used to determine the effect of the wire by which it is suspended on the time of oscillation of a ball-pendulum. If it be proposed to determine the state of motion of the fluid due to a uniform translation of the cylinder, it will be found that a steady motion of the fluid will be impossible, but that as the time increases the quantity of fluid carried forward with the cylinder continually increases. In fact, if the differential equation for the stream function be integrated on the supposition of steady motion, it will be found that, though the integral takes a simple finite form, there are not arbitrary constants sufficient to satisfy the conditions.

Plane and Disc.—The determination of the motion of a disc in a viscous fluid is important, as it forms a useful method to determine experimentally the value of the coefficient of viscosity for different fluids. The method was first employed by Coulomb, but first received mathematical treatment by Stokes (1850), and afterwards (1861) by Meyer. Stokes [1] begins by investigating the motion when an infinite plane oscillates in its own plane, so that its displacement at any time is given by $c \sin nt$. The displacement at any point in the fluid at a distance x is then given by $c \sin \{nt - x\sqrt{(n/2\mu)}\} \times \exp - x\sqrt{(n/2\mu)}$. A given phase is therefore propagated with a velocity $\sqrt{2\mu n}$. This for air, treated as incompressible, andfor a time of vibration of one second, is about ·2908 inch per second. The solution for a disc oscillating in its own plane can then be obtained by treating each element of it as a portion of the above plane, a solution which is exact if the squares of the velocities are neglected, except in so far as the action of the rim is concerned. In this way he finds the change in the time of vibration due to viscosity, and also the logarithmic decrement of the arc of oscillation, with a correction to be applied, because the observations are made soon after the disc is set in motion, and before the motions, due to the starting in a fluid at rest, have disappeared. The results obtained enable him to discuss the observations of Coulomb.

Without a knowledge of Stokes' work, O. E. Meyer [2] attacked the same problem about ten years later. He supposes the angular velocity of the fluid to depend only on the distance from the disc, and not on the distance from the axis of rotation. This is equivalent to Stokes' application of the motion for a plane to that for a disc. He also determines the logarithmic decrement.

The Sphere.—The analytical difficulties connected with this surface may be considered to have been surmounted, chiefly through the work of Stokes, Meyer, and Oberbeck. In his second paper on viscosity of fluids Stokes [1] attacks the problem of the motion by expressing the velocities in terms of the stream function—first introduced by him—and making the determination of this stream function the basis of the investigation. The motion is supposed so small that squares and products of the velocities may be neglected. In this case the stream function ψ must satisfy the differential equation [3] $\nabla^2(\nabla^2 \times \rho\mu^{-1}d/dt)\psi = 0$, the solution of which can be represented in the form $\psi = \psi_1 + \psi_2$ where $\nabla^2\psi_1 = 0$, $(\nabla^2 + \rho\mu^{-1}d/dt)\psi_2 = 0$. The complete solution of this is not entered

[1] 'On the effect of the internal friction of fluids on the motion of pendulums,' *Camb Phil. Trans.* ix. part 2, p. 8 (1850).

[2] 'Ueber die Reibung der Flüssigkeiten,' *Borch.* lix. p. 229.

[3] I use $-\nabla^2$ to denote the operation $d^2/dx^2 + d^2/dy^2 + d^2/dz^2$, or, in this case, $d^2/dx^2 + d^2/d\varpi^2 - \varpi^{-1}d/d\varpi$, as ∇ denotes the vector operator $id/dx + jd/dy + kd/dz$.

upon, but the simpler and more important case where the motion begins from rest is worked out in detail. If the displacement of the centre of the sphere be given by the equation $\xi = c \sin nt$, then the stream function, when the surrounding fluid is infinite, is

$$\psi = \tfrac{1}{2} a^2 c \sin^2\theta \Big[\Big\{ \Big(1 + \frac{3}{2\nu a}\Big) \cos nt + \frac{3}{2\nu a}\Big(1 + \frac{1}{\nu a}\Big) \sin nt \Big\} \frac{a}{r}$$

$$- \frac{3}{2\nu a} \Big\{ \cos (nt - \nu r + \nu a) + \Big(1 + \frac{1}{\nu r}\Big) \sin (\ldots) \Big\} e^{-\nu(r-a)} \Big]$$

where $\nu = \surd(n/2\mu)$, whence the pressure and resultant force on the sphere are easily deduced in simple forms. The latter consists of two terms, whose effects on the motion of a pendulum are different. If τ is the time of oscillation, the effect of one term is to produce an apparent increase of inertia equal to $k\mathrm{M}'$, whilst the other has most effect on the amplitude of vibration, the log decrement being $\frac{\pi}{2\tau} \cdot \frac{k'\mathrm{M}'}{\mathrm{M} + k\mathrm{M}'}$, where M, M' denote the masses of the sphere, and of the fluid displaced by it, and

$$k = \tfrac{1}{2} + \frac{9}{4a}\sqrt{\frac{2\mu\tau}{\pi}},\ k' = \frac{9}{4a}\Big(1 + \sqrt{\frac{2\mu\tau}{\pi a^2}}\Big)\sqrt{\frac{2\mu\tau}{\pi}}.$$

He then passes on to investigate the effect of a concentric spherical boundary. When the effect of the boundary is small it is sufficient to treat it as absent, and then add small corrections to the results. If the viscosity is small, or if the time of oscillation is small, this correction is the same as if there were no viscosity.[1]

We have seen (p. 27) that a *steady* motion of the fluid when a cylinder moves uniformly through it is impossible. This is not so with the sphere. In this case Stokes shows, that, if V be the velocity of the sphere, $\psi = \frac{1}{4} a^2 \mathrm{V}(3r/a - a/r) \sin^2\theta$ (axes fixed in the sphere), and that the force necessary to maintain the motion is $6\pi\mu a\mathrm{V}$. This varies only as the radius of the sphere, 'accordingly, fine powders remain nearly suspended in a fluid of widely different specific gravity.' If a sphere of density σ be descending through a fluid under gravity, the limiting velocity (if it is not very great) is $2g(\sigma - \rho)a^2/9\mu'$; this for a globule of water in air, of ·001 inch diameter, is 1·593 inch per second, whilst for one with a diameter of ·0001 inch, it is less than one-sixteenth of an inch per second.

In a note at the end of this paper it is shown that if a sphere rotate about a diameter the particles of the fluid move, when the motion is steady, in annuli, with velocities given by $v = a^3\omega \sin\theta/r^2$, ω being the angular velocity of the sphere; and that, in general, the motion is given by $v = v' \sin\theta$, where v' is a function of r alone. This steady motion in annuli is only possible when the motion is slow; if it is not so, then with the annular motion is combined one in planes through the axis: 'In fact it is easy to see that, from the excess of centrifugal force in the neighbourhood of the equator of the revolving sphere, the particles in that part will recede from the sphere and approach it again in the neighbourhood of the poles, and this circulating motion will be com-

[1] See above, p. 51.

bined with a motion about the axis.'[1] This may be compared with Boussinesq's results for a circular tube of rectangular section, referred to above.

This investigation by Stokes is a most important one, forming as it does the first application of mathematical reasoning with any success to the problem of the motion of pendulums in non-perfect fluids. The second part of the paper, forming about one-third of the whole, is devoted to the discussion of the observations of Baily, Bessel, Coulomb, and Dubuat, and the values of μ for water and air are deduced from their experiments. The investigations with reference to cylinders and vibrating discs have been already referred to.

Stokes had considered the case when the fluid was originally at rest without vortex motion in any part, and had, therefore, taken only those particular solutions of the differential equations which ψ_1, ψ_2 satisfy, in which θ enters as the factor $\sin^2\theta$. In 1870, O. E. Meyer[2] took up this question and showed that the general solutions are expressed in the forms

$$\psi_1 = \Sigma(A\Theta_n + BZ_n)R_n \exp(\lambda^2 t), \; \psi_2 = \Sigma(C\Theta_n + DZ_n)S_n \exp(\lambda^2 t)$$

where Θ, Z are functions of θ alone, and R, S of r, both of finite forms. In fact, the Θ, Z are proportional[3] to $\sin\theta dP/d\theta$, where P is a zonal spherical harmonic. The work is too complicated to be described with any fulness here, but it is carried out with much skill, account being taken of a concentric boundary. He proves, amongst other things, that the motion due to the original state of the fluid decreases indefinitely with the time, *i.e.*, that the equation giving the values of λ has all its roots pure imaginaries except for the case $n = 1$ or $\Theta_1 = \sin^2\theta$ (Stokes' case), in which it is complex, giving periodic vibrations with decreasing amplitudes. In the particular case where the external boundary is infinitely large, Meyer's results agree with those of Stokes for the time, but there is a slight difference for the log decrement. When the surrounding fluid is elastic the results must be modified; this has also been considered by Meyer[4] who has determined the log decrement under these conditions, and has shown that when the velocity of sound in the fluid is very great the correction may be neglected without sensible error. Meyer refers to a paper by C. J. H. Lampe[5] on the same subject, but this I have not seen.

The investigations both of Stokes and Meyer are based on the stream function, but this is only suitable when the motion takes place in planes through an axis. When this is not so, recourse must be had to the quaternion potential first introduced by Helmholtz[6] in his paper on vortex motion. The investigation on these lines has been carried out by

[1] 'On the theories of the internal friction of fluids in motion,' &c. *Camb. Phil. Trans*, viii.; or reprint, vol. i. p. 103, 1845. The connection of this with part of Siemens' theory of the conservation of the sun's heat is evident.

[2] 'Ueber die pendelnde Bewegung einer Kugel unter dem Einflusse der inneren Reibung des umgebenden Mediums,' *Borch.* lxxiii. p. 31.

[3] 'Ueber die Bewegung einer Pendelkugel in der Luft,' *Borch.* lxxv. p. 336, 1873.

[4] *Ibid.*

[5] 'Ueber die Bewegung einer Kugel, welche in einer reibenden Flüssigkeit um einen senkrechten Durchmesser als feststehende Axe rotirend schwingt,' *Programme des Städtischen Gymnasiums zu Danzig*, 1866.

[6] See Part I. of this report, *Brit. Assoc. Rep.* 1881, p. 60.

Oberbeck,[1] and later and independently by Craig.[2] As is known the velocities are in this method expressed by functions P, L, M, N, so that $u = dP/dx + dN/dy - dM/dz$ with $\nabla^2 P = 0$. $dL/dx + dM/dy + dN/dz = o$, and the vortex rotations given by $\xi = \nabla^2 L$, &c. He takes the most general form for P in spherical harmonics with no normal velocity at the surface of the sphere; in other words, if Y_n be any solid harmonic of degree n, then

$$P = \Sigma \left\{ 1 + \frac{n}{n+1}\left(\frac{a}{r}\right)^{2n+1} \right\} Y_n.$$

By means of an important theorem of Borchardt's, L, M, N are then expressed in the form $L = z\,dF/dy - y\,dF/dz$, with similar expressions for M, N, where

$$F = \tfrac{1}{2}\Sigma \frac{2n+1}{n+1}\left(\frac{a}{r}\right)^{2n+1}\left(1 - \frac{a^2}{r^2}\right) Y_n.$$

The above theory applied to a sphere moving uniformly gives values for the velocities which agree with those of Stokes. Expressions are also given for the vortex rotations, from which it can be easily proved that the vortices of equal strength lie on concentric spheres, and that the strengths are inversely as the squares of the radii of the spheres on which they lie. The theory given by Craig is almost identically the same, as indeed any theory, starting from the basis of Borchardt's theorem and the quaternion potential, must be.

The motion of fluid inside a sphere was first investigated by Helmholtz,[3] allowance being made for a slipping of the fluid over the surface of the boundary. The paper in which his investigation appeared was a joint one, containing the mathematical theory by Helmholtz, and the experimental by Piotrowski. The motion is considered so small that squares of the velocities may be neglected, and in this case the motion is such that it may be represented by supposing concentric shells of the fluid to revolve as if rigid with an angular velocity depending on the radius of the shell, the most general expression for which is a sum of terms of the form

$$\omega_a = A e^{at} \left\{ \frac{\beta}{r^2} \cosh \beta r - \frac{1}{r^3} \sinh \beta r \right\} \text{ where } \beta = \pm \sqrt{(a/\mu')},$$

and a is in general a complex. The motion can be represented as a series of waves propagated to the centre with rapidly decreasing intensity, and there reflected. If, for example, the boundary have a simple harmonic motion of period τ, the velocity of propagation of these waves will be $2\sqrt{(\mu\pi/\tau)}$, and is therefore dependent on the time of vibration. Whilst the wave moves through a wave-length $2\sqrt{(\mu\pi\tau)}$, the amplitude diminishes in the ratio 1 to exp.(-2π), or from 1 to 1/535. Helmholtz works out the motion for the sphere as applicable to the data in Piotrowski's experiments. These experiments contain the first attempt to approximate to the value of the coefficient of gliding. The values of this found for alcohol and ether are so small that they are probably

[1] 'Ueber stationäre Flüssigkeitsbewegungen mit Berücksichtigung der inneren Reibung,' *Borch.* lxxxi. p. 62, 1875.

[2] 'On steady motion in an incompressible viscous fluid,' *Phil. Mag.* (5) x. p. 342 (1880)

[3] 'Ueber Reibung tropfbarer Flüssigkeiten,' *Sitzber. d. k. Akad. Wiss. Wien.*, xl. p. 607 (1860), and *Wissenschaftlichen Abhandlungen*, i. p. 172.

evanescent, whilst for water in contact with a gilded surface it is considerable.

The same problem has been investigated by Lübeck [1] (1873), starting from Meyer's solution of the equation for the stream function, and by Rohrs [2] (1874), who took up the question from the point of view of precession, and considers the case where the axis of rotation slowly changes.

The Ellipsoid.—The expressions for the velocities when a sphere moves through a viscous fluid have suggested to Oberbeck [3] the form of the solution for an ellipsoid moving parallel to one of its axes. He shows that if Ω denote the potential of the ellipsoid at an external point, in the form given on page 17, and $Q = 2\pi\int_0^\infty \frac{d\lambda}{D}$, then the velocities of the fluid, when the ellipsoid moves parallel to the axis a with velocity V, are given by

$$u = V + \alpha\left\{x\frac{dQ}{dx} + a^2\frac{d^2\Omega}{dx^2}\right\}$$

$$v = \alpha\left\{x\frac{dQ}{dy} + a^2\frac{d^2\Omega}{dxdy}\right\}$$

$$w = \alpha\left\{x\frac{dQ}{dz} + a^2\frac{d^2\Omega}{dxdz}\right\}$$

where $$\alpha = \frac{V}{Q_0 + a^2A} \text{ with } A = \frac{2\pi}{a^2}\int_0^\infty \frac{d\lambda}{\left(1 + \frac{\lambda^2}{a^2}\right)D}.$$

The force on the ellipsoid necessary to keep up uniform motion is then $8\pi\mu'\alpha\epsilon$, where ϵ is the measure of the charge of electricity induced on the ellipsoid when it is charged to potential Q_0.

The oscillations of a viscous spheroid have been treated by G. H. Darwin and Lamb. In the investigations of the former,[4] which are devoted more directly to researches on the past history of the earth, the motions are treated as very slow, and the coefficient of viscosity as large, so that the problems considered belong more to the domain of elastic solids than to that of hydrodynamics. The latter [5] has considered the general solution of the equations of motion when the velocities are so small that their squares can be neglected. The first part of his paper is devoted to the solution of the system of equations

$$(\nabla^2 - h^2)u = 0, (\nabla^2 - h^2)v = 0, (\nabla^2 - h^2)w = 0, \text{ and}$$
$$du/dx + dv/dy + dw/dz = 0.$$

This is then applied to investigate the oscillations of a sphere slightly distorted and moving under its own gravitation, and an equation is obtained on whose roots depend the time of oscillation and the logarithmic decrement of the amplitude. This equation is easily solved either for the

[1] 'Ueber den Einfluss, welchen auf die Bewegung eines Pendels mit einem kugelförmigen Hohlraume eine in ihm enthaltene reibende Flüssigkeit ausübt,' *Borch.* lxxvii. p. 1.

[2] 'Spherical and cylindric motion in viscous fluid,' *Proc. Lond. Math. Soc.*, v. p. 125.

[3] 'Ueber stationäre Flüssigkeitsbewegungen,' &c. *Borch.* lxxxi. p. 62.

[4] 'Bodily tides of viscous spheroids,' *Phil. Trans.*, part i. 1879.
'Problems connected with tides of a viscous spheroid,' *Phil. Trans.* part ii. 1879.

[5] 'On the oscillations of a viscous spheroid,' *Proc. Lond. Math. Soc.* xiii. p. 51, 1881.

case of very large viscosity or very small. For very large viscosity the result agrees with that of Darwin's and the displacement subsides without oscillation. For very small, the time of oscillation agrees with that for a perfect fluid, found by Thomson,[1] whilst the 'modulus of decay,' *i.e.* the time in which the amplitude decreases to $1/e$ of its original value, is $(n-1)(2n+1)\mu/a^2$, for an harmonic displacement of order n. This for a sphere of water of the size of the earth is $1{\cdot}84 \times 10^{11}$ years. For a globule of water oscillating under the action of its surface tension, the time of oscillation is $2\pi/\beta$, where $\beta^2 = n(n-1)(n+2)\mathrm{T}/\rho a^3$ where T is the surface tension. For the slowest oscillation ($n = 2$) the modulus of decay of a globule of water is $14{\cdot}3\ a^2$ seconds, the radius a being expressed in centimetres.

The effect of viscosity on the motion of waves has been discussed by Stokes,[2] Boussinesq,[3] Lamb,[4] and others. The rate of decay of the motion obtained by Stokes is double the true value—an error caused, as both Boussinesq and Lamb have pointed out, by an oversight of the former in neglecting the potential energy of the motion.

Postscript.

I find I have omitted to notice a paper by Lodge 'On some Problems connected with the Flow of Electricity in a Plane,' *Phil. Mag.* (V.), vol. l. (1876), in which the motions in plane triangles, rectangles, and circles are treated.

Report of the Committee, consisting of Professor G. Carey Foster, *the late* Mr. C. Hockin, Sir William Thomson, Professor Ayrton, Mr. J. Perry, Professor W. G. Adams, Professor Lord Rayleigh, Professor F. Jenkin, Dr. O. J. Lodge, Dr. John Hopkinson, Dr. A. Muirhead (*Secretary*), Mr. W. H. Preece, Mr. Herbert Taylor, Professor Everett, *and* Professor Schuster, *appointed for the purpose of constructing and issuing practical Standards for use in Electrical Measurements.*

The Committee have to report that Mr. Taylor has continued the experiments upon the temperature-coefficient of the resistance of metals and alloys, the first results of which were communicated at the York meeting. In consequence of Mr. Taylor's absence from the country, the details of the further experiments cannot be communicated at present; but it may be stated that they have shown the possible influence of the process of

[1] See above p. 24.
[2] 'On the effect of the internal friction,' &c., cited above.
[3] 'Additions et éclaircissements au mémoire intitulé Essai sur la théorie,' &c. *Mém. de Sav. Etran.* xxiv. (1877).
[4] 'On the oscillations,' &c., cited above.

annealing on the specific resistance of wires and on the temperature-coefficient to be much greater than has hitherto been commonly supposed. The following are examples of some of the results obtained:—

German Silver.—Wire drawn to be extremely hard and brittle. The percentage variation of resistance, for 1° between 13° and 100° C., was 0·0296. After annealing, the percentage variation of the same wire was 0·0421.

Steel.—Wire, 0·025 inch diameter, thoroughly hardened, and then tempered in paraffin wax at 230° C.:—

Percentage variation of resistance for 1°, 0·267.

Same wire annealed; percentage variation for 1°, ·316.

At 9° C., the ratio of the absolute resistance of this wire in the hard state to that of the same wire when annealed was 1·229.

Platinum-Silver Alloy.—A piece of wire made from a particular bar of the alloy was hardened by being drawn down through a couple of holes of the draw-plate. In this state the variation of resistance was 0·0255 per cent. per degree. After annealing in the ordinary way, the variation of resistance per degree was 0·0258 per cent. The same wire was next placed in an iron tube which was filled up with sand and left all night in the fire. After this treatment, the percentage variation of resistance per degree was 0·0344.

Platinum-Silver Alloy, another specimen.—A wire from a second bar of the alloy was annealed at a very high temperature and left to soak in the fire and cool slowly, as in the last-mentioned experiment. The variation of resistance was now 0·095 per cent. per degree, and the wire was as soft as pure silver and very fragile. After being heated to redness and quenched in water, the corresponding variation of resistance of the same wire was 0·076; and when the wire had been drawn down through two or three jewel-holes, it was 0·0732.

These results indicate a connection between the temperature-coefficient of wires and their degree of hardness, and tend to reopen the question as to the most trustworthy material for a permanent standard of resistance. The Committee understand that Mr. Taylor will continue his experiments with the co-operation of Dr. Muirhead.

The Committee are pleased to be able to report that there is a prospect that Lord Rayleigh may be able to organise, at the Cavendish Laboratory, Cambridge, a system of testing resistance-coils and issuing certificates of their correct value at a specified temperature.

As stated in the Report presented last year, Dr. Muirhead has consented, at the request of the Committee, to issue standards of capacity upon his own responsibility.

The Committee regret that they are not able to report any progress towards the construction of a standard of Electromotive Force.

They are unwilling to conclude without expressing their deep sense of the loss which not only they, but all friends of physical science, have suffered in the death of one of the most valued of their colleagues, Mr. Charles Hockin.

Fifteenth Report of the Committee, consisting of Professor EVERETT, Professor Sir WILLIAM THOMSON, Mr. G. J. SYMONS, Sir A. C. RAMSAY, Professor A. GEIKIE, Mr. J. GLAISHER, Mr. PENGELLY, Professor EDWARD HULL, Dr. C. LE NEVE FOSTER, Professor A. S. HERSCHEL, Professor G. A. LEBOUR, Mr. A. B. WYNNE, Mr. GALLOWAY, Mr. JOSEPH DICKINSON, Mr. G. F. DEACON, Mr. E. WETHERED, *and* Mr. A. STRAHAN, *appointed for the purpose of investigating the Rate of Increase of Underground Temperature downwards in various Localities of Dry Land and under Water. Drawn up by* Professor EVERETT (*Secretary*).

ONE portion of the duty assigned to the Committee is the investigation of the rate of increase of underground temperature downwards *under water.* This part of their task has remained in abeyance until the past year, but through the good offices of Professors Lebour and Merivale observations have now been obtained from a colliery which runs to a considerable distance under the sea at Whitehaven, Cumberland.

The observations were taken in holes bored upwards for the purpose to a distance of 4 feet in the roof of the 'Main Band,' at Croft Pit, under the direction of the manager, Mr. G. H. Liddell.

The holes were well plugged with clay, and the thermometer (one of the Committee's slow-action instruments) was in each case left in the hole for 7 days. The distance beyond low-water mark was 430 yards in the case of two of the boreholes, and 1,340 yards in the case of the other two. The depths below ordnance datum were 1,140 feet for the two former, and 1,250 feet for the two latter. The depth of the sea in all four cases is estimated at 12 fathoms. The temperature observed was exactly the same in all four holes, namely, 73° F., and, in one instance, this was verified by reinserting the thermometer with its bulb upwards instead of downwards. These data give 1,195 feet as the mean depth below ordnance datum, and 1,123 feet as the mean depth below the bottom of the sea. Assuming 48° as the mean temperature of the bottom of the sea, we have, therefore, an increase of 25° F. in 1,123 feet of ground, which is at the rate of 1° F. in 45 feet.

Mr. E. Garside has furnished two more observations, one of them from the same neighbourhood as his previous observations—the East Manchester coal-field—and the other from South Staffordshire. They were made with the slow-action thermometer, used in precisely the same manner as before.

The former observation was taken on May 4, 1882, in Denton Colliery, Lancashire. The hole was drilled at 1,317 feet from the surface, nearly vertically below the bed of the river Tame, which divides the estate of Denton Colliery from that of Bredbury Colliery, and the temperature observed was 66° F. Assuming a surface temperature of 49°, this gives an increase of 17° in 1,317 feet, which is at the rate of 1° in $77\frac{1}{2}$ feet, being nearly identical with that found at Bredbury Colliery.

The other observation was made at Lye Cross Colliery, Dudley (north of Wolverhampton). The thermometer was placed, as usual, in a hole about 4 feet deep, drilled for the purpose in ground newly opened, free from cracks or other visible irregularities, and also free from any strong air-current. It was at the depth of 700 feet from the surface, in the hard

shales which are 8 feet in thickness, forming the floor of the ten yards coal and roof of the Heythen coal, the total thickness of the seam worked (with small parting) being about 52 feet. The temperature observed was 57°·5 F. which, with an assumed surface temperature of 49°, gives an increase of 8°·5 in 700 feet, being at the rate of 1° F. in 82 feet.

The colliery is situated on the summit of a hill 822 feet above sea-level, so that the point at which the observation was taken was 122 feet above sea-level. The convexity of the ground must be taken into account as one element in endeavouring to account for the slowness of the observed rate of increase. Of the 700 feet of superincumbent shales, about 470 consist of coal measures, 165 of clay marl, and 65 of basalt, connected with dykes whose many branches traverse the coal at slopes varying from vertical to horizontal. The basalt is found to contain, when newly cut open, a remarkable quantity of salt water; and the charred coal next to the dyke is as porous as ordinary coal cinders for a distance of several inches from the dyke.

The Secretary has had a correspondence with Mr. Garside respecting the quantity of water found in the East Manchester coal-field. This quantity is very large, as appears from a list furnished by Mr. Garside of the number of gallons pumped per minute from each of thirteen pits during the sinking, the list being given on the authority of William Seddon, Esq., mining engineer, who was contractor for the sinking of them. The average is 360 gallons per minute for each pit, the highest being Denton Colliery with 1,000 gallons, and the lowest Valley Pit, Denton, with 120 gallons. Particulars are also given of the quantity now pumped from some of the collieries, amounting in some cases to 800 or 900 gallons per minute. Some of the collieries have been repeatedly flooded, and one is mentioned (Lord's Field Colliery) which was abandoned on account of water, though its owners were makers of hydraulic machinery, and tried their utmost to keep the water down. Some of the pits were formerly the sources of water-supply for towns in the district. In Astley Deep Pit, Dukinfield, the shaft is 'tubbed' with cast-iron rings to keep the water back; and most of the shafts in the district are made as water-tight as possible. Mr. Garside refers to the 'Memoir of the Geological Survey round Oldham,' as stating, on page 45, that five million gallons a day are estimated as being raised from the New Red Sandstone.

The question naturally arises whether this abundance of water does not exert a powerful convective action, and furnish the explanation of the slow increase of temperature downwards, which has been observed not only in the coal mines of this district but also in a still more marked degree at the Liverpool waterworks at Bootle.

Nine years having elapsed since the last observations were furnished from the great well at La Chapelle in the north of Paris, which was then in course of sinking, the Secretary has put himself in communication with the contractors to learn what progress has been made, and has received a letter dated July 8, 1882, giving a history of the undertaking during the interval.

The continual crumbling down of the sides rendered tubing necessary, and a tube was accordingly constructed 677m. long, 1·3m. in diamete and 2 centimetres thick. During the lowering of it, a portion 120 long broke off and fell to the bottom, leaving another piece 100m. suspended. This suspended piece was successfully extracted w difficulty, but the fallen piece was not easily dealt with. It was

into four lengths by a new and special tool, and three of these were raised; but the fourth was so broken and jammed that the extracting tool could not remove it. Dynamite was tried, but its explosive violence was so deadened by the superincumbent pressure, that it proved powerless, and a special engine had to be constructed for crushing the broken pieces. This task has now been successfully accomplished, and the work is accordingly just as forward as it was before the tubing was commenced. The Municipal Council of Paris have now ordered the continuance of the operations, and the tubing will be recommenced. Owing to the difficulties above described, the well is now no deeper than it was when the last observations of temperature were taken in it nine years ago.

Two slow-action thermometers have been sent to Mr. W. Galloway (Member of the Committee and Inspector of Mines, Cardiff), for observations in mines.

One slow-acting and one Negretti maximum thermometer have been sent to Mr. T. W. Rumble, Engineer of the Southwark and Vauxhall Water Company, for observations in a deep well now sinking at Tooting.

A slow-acting thermometer has also been supplied to Mr. Griffith, Manager of a Colliery at Wrexham.

This, the fifteenth Report of the Committee, is accompanied by a summary, which has been made by the Secretary, of the fourteen preceding Reports, together with as much as it was possible to include of the present Report.

Summary of Results contained in the First Fifteen Reports of the Underground Temperature Committee. By Professor Everett (*Secretary*).

The fourteen reports hitherto published are contained in the consecutive volumes of British Association Reports, commencing with that for 1868, except that the report for 1874 having been by mistake omitted from the volume for that year, is inserted in the volume for 1875 instead.

The following Table, showing the page at which each report commences, will facilitate reference:—

Report	Volume	Page	Report	Volume	Page
I.	1868	510	VIII.	1875	156
II.	1869	176	IX.	1876	204
III.	1870	29	X.	1877	194
IV.	1871	14	XI.	1878	178
V.	1872	128	XII.	1879	40
VI.	1873	252	XIII.	1880	26
VII.	1874	14	XIV.	1881	90

In the references which we shall have to make, the number of the report will be indicated by Roman, and the page by Arabic figures.

We shall classify the results as follows:—

A. Instruments. B. Methods of observation. C. Questions affecting correctness of observations. D. Questions affecting deductions from observations. E. Comparison of results. F. Mean rate of increase of temperature with depth, and mean upward flow of heat.

A. Instruments.—Under this head we have—

Instruments for observing temperature. 2. Subsidiary apparatus.

The thermometers which the Committee have employed have been

of two kinds—slow-action thermometers and maximum thermometers. The present pattern of slow-action thermometer consists of a thermometer having its bulb surrounded by stearine or tallow, the whole instrument being hermetically sealed within a glass jacket, and had its origin in a conference between the Secretary and Dr. Stapff in the St. Gothard tunnel (VIII., IX., XI.) Other slow-action methods described in the reports are—Ångstrom's thermometer in bottle of water (I.), large spirit thermometer (I.), Symons' thermometer in a thick casing of felt (II.).

Our present patterns of maximum thermometer are two—the Phillips, and the Inverted Negretti—both being hermetically sealed in strong glass jackets to prevent the bulbs from receiving pressure when lowered to a great depth in water.

Both instruments are used in a vertical position, and it is necessary that they register truly in spite of jolts in hauling up. The Phillips pattern was used first (I., II., III.), and there were continual complaints of the detached column shaking down, till it was pointed out by Professor Phillips himself, that the fault arose from the bore not being small enough. This defect was remedied (VI.), and the instrument has since worked perfectly, but it requires good light and sharp eyes to read it.

The Inverted Negretti (IV.) was contrived by the Secretary with the view of overcoming the difficulty as to jolts, but the contrivance had been anticipated many years before by Messrs. Negretti & Zambra themselves. It is easily read and managed, but it has a theoretical defect in requiring a slight correction for the difference between the temperature at the time of taking the reading and the maximum temperature recorded.

References to some other kinds of maximum thermometer will be found in some of the reports, namely, to Walferdin's (IV.), Lubimoff's (IV., V.), and Magnus' (IX.), all these being of the class of overflow thermometers.

References to Becquerel's thermo-electric method of observing underground temperature were made in three of the reports (I., XI., XII.), and some laboratory experiments were subsequently carried out by the Secretary which led to the conclusion that the method could not be relied on to yield sufficiently accurate results. It may be mentioned that Becquerel's observations are only carried to the depth of 100 feet, whereas we require observations at the depth of 1,000 or 2,000 feet.

2. As regards subsidiary (that is non-thermometric) apparatus, Mr. Symons' apparatus for lowering and raising thermometers to and from any required depth in a deep well (1,000 feet deep in this case), is described with an illustration in the second report.

Plugs for preventing convection-currents in a bore or well are suggested in the first report. Herr Dunker's two forms of plug successfully employed by him at Sperenberg, are described in the ninth, and Professor Lebour's umbrella-like plug in the ninth, tenth, and twelfth. In its final form (XII.) it appears to be very convenient, as it requires only one wire. It remains collapsed so long as the wire is taut, but opens out and plugs the hole when it becomes slack.

B. Methods of Observation. These have chiefly been of two kinds.

1. Observations in holes bored to the depth of a few feet in newl opened rock, either in the workings of a mine or a tunnel, or in a sh during the sinking. The rock should not have been exposed for r than a week when the hole is bored, and a day may be allowed to for the heat generated by boring to escape before the thermom

inserted. Very complete plugging is necessary to exclude the influence of the external air. It is desirable to use about two feet of plugging, of which the outer part should be made airtight with plastic clay or greased rag. After the lapse of a few days, the thermometer is to be drawn out by means of a string attached to the handle of its copper case, and the reading taken. The slow-action thermometer above described is employed for this purpose, and there is time to read it with sufficient deliberation before any appreciable change occurs in its indication. It is recommended that the thermometer be then reinserted and plugged as before, and a second reading taken after the lapse of a week. The majority of our successful observations have been made by this method.

2. Observations in deep bores of small diameter.

The first report contained a successful application of this method to a bore about 350 feet deep, near Glasgow, which gave very regular results in a series of observations at every sixtieth foot of depth; but in the majority of instances in which it has since been applied, there have been marked irregularities, due apparently to the influx of water from springs at particular points. One of the most valuable of our results was obtained by the application of the method to a bore 863 feet deep, executed at the bottom of a coal mine 1,066 feet deep, giving a total depth of 1,929 feet. The bore in this case was dry at the time of its execution, though full of water at the time of the observation. It was in South Hetton Colliery, Durham, and the observer was Mr. J. B. Atkinson (V., VI.). The instrument generally employed in the observations of this class was a maximum thermometer of either the Phillips or the Inverted Negretti construction, as described above.

The larger the diameter of the bore the more uncertain does this mode of observation become. The South Hetton bore had a diameter of $2\frac{1}{2}$ inches. The Kentish Town well, 1,000 feet deep, in which Mr. Symons' observations were made, had a diameter of 8 inches (II., III., IV.), and the well 660 metres deep at La Chapelle, in the north of Paris, had a diameter of $4\frac{1}{2}$ feet (V., VI., VII.). The temperatures in this last were proved to be largely affected by convection, the water at the top being too warm, and that at the bottom not warm enough. The observations of Herr Dunker, in the bore at Sperenberg, near Berlin, with a depth of 3,390 feet and a diameter of 12 inches, proved a similar disturbance, amounting at the top and especially at the bottom to several degrees. As regards the bottom, the proof consisted in showing that when a thermometer at the bottom was protected by a tight plug from the influence of the water above, its indications were higher by 3° R. ($= 6\frac{3}{4}$° F.), than when this precaution was not employed.

3. Where a shaft contains only a few feet of water at the bottom, a thermometer lowered to the bottom of this water may be assumed to give pretty nearly the normal temperature of the soil at this depth, and a few of our observations have been taken in this way. No observations of any value for our purpose can be made in the portion of a shaft or well occupied by air, as the temperature of such air is largely influenced by that of the air at the surface. This is clearly proved by Mr. Symons' observation in 200 feet of air at Kentish Town (II., III.).

C. QUESTIONS AFFECTING THE CORRECTNESS OF THE OBSERVATIONS MADE
ght theoretically include questions as to the correct working of the
uments employed, and as to the personal reliability of observers; but
tter topic has not come into discussion, and the former has not arisen

since our present patterns of instrument came into use. The questions for discussion are thus confined to those which relate to possible differences between the temperature of the point at which the thermometer was placed and the normal temperature at the same depth in its vicinity.

1. The heat generated by the action of the boring tool will vitiate the observation if sufficient time is not allowed for its escape.

A very full discussion of this subject in connection with the great artesian well at La Chapelle will be found in reports V., VI., and VII., clearly establishing the fact that the temperature at the bottom both on the third and the sixth day after the cessation of boring operations, was $7\frac{1}{4}$° F. higher than after the lapse of four months, though the water had been left to itself during this interval. Further evidence showing that the temperature in the lower part of a bore full of water may thus be raised several degrees, is furnished by the Sub-Wealden bore (VI. 255).

The heat generated by boring will increase with the hardness of the rock, and Mr. Garside, in report XIV., testifies that he has found two hours a sufficient time to give the permanent temperature in holes $3\frac{1}{2}$ feet deep and 2 inches in diameter drilled in the sides of a deep mine in the East Manchester coalfield.

2. The generation of heat by local chemical action is well known to be a powerful disturbing cause when pyrites is present. In the tenth report, the observers in the mines of Schemnitz say, 'Pyrites and also decaying timber were avoided, as being known to generate heat.' In the ninth report, p. 210, the observations in the coal mines of Anzin show a temperature of $70\frac{3}{4}$° F. in shaft IV. (a very dry one) at the depth of 21·2 metres, or less than 70 feet. This must be about 15° F. above the normal temperature. In shaft II. the observer mentions that there was at a depth of 90 m. a seam of coal in which heat was generated by oxidation.

At Talargoch lead mine in Flintshire (XIII., XIV.), the discrepancies between the temperatures at the six observing stations are suggestive of local chemical action.

3. Convection of heat has proved a very troublesome disturbing cause.

As to convection of heat by air in a shaft or well not filled with water, evidence will be found in the second report, both in the case of Mr. Hunter's observations in the shafts of two salt mines at Carrickfergus, having the depths of 570 and 770 feet respectively, and in the case of Mr. Symons' observations at Kentish Town, where the first 210 feet of the well are occupied with air. At the depth of 150 feet the temperature was 52·1 in January and 54·7 in July.

Convection of heat by water in old shafts which have been allowed to become flooded, is very manifest in some of the observations communicated by Mr. Burns in the second and fourth reports. In Allendale shaft (Northumberland), 300 feet deep, with about 150 feet of water, the temperature was practically the same at all depths in the water, and this was also the case in Breckon Hill shaft, where the observations extended from the depth of 42 feet to that of 350 feet. A similar state of things was found in a shaft at Ashburton (Devon), by Mr. Amery (III. 7), who observed at every fiftieth foot of depth down to 350 feet.

Convection by water in the great well at La Chapelle, 660 m. (2,165 feet) deep, and 1·35 m. (4 feet 5 inches) in diameter at the bottom, appears probable from the following comparisons.

Very concordant observations (communicated by M. Walferdin to *Comptes Rendus* for 1838) at three different wells in the Paris basin of

the respective depths of 263 m. 400 m. and 600 m., show, by comparison with one another and with the constant temperature in the artificial caves under the Paris Observatory, a rate of increase of 1° F. in 56 or 57 feet (IV. 24, 25). These data would give at the depth of 100 m., or 328 feet, a temperature of 57°, and at the depth of 660m., or 2,165 feet, a temperature of 90° ; whereas the temperatures actually observed at those depths in the well at La Chapelle in October 1873, when the water had been undisturbed for a year and four months, were 59°·5 and 76° (VI. 254). It thus appears probable that the upper part of the well is warmed, and the lower part cooled, by convection. Further light may be expected to be thrown on this point when the well reaches the springs, and the water spouts above the surface, as it does at the Puits de Grenelle. A letter received by the Secretary in July 1882 states that engineering difficulties have prevented any deepening of the well since the above observations, but that arrangements for this purpose have now been made.

More certain and precise information as to the effect of convection in deep bores is furnished by the experiments of Herr Dunker at Sperenberg (IX. 204–208). The principal bore at Sperenberg has a depth of 4,052 Rhenish, or 4,172 English feet, and is entirely in rock salt, with the exception of the first 283 feet. Observations were first taken (with a maximum thermometer on the overflow principle) at numerous depths, from 100 feet to the bottom, and showed a fairly regular increase of temperature downwards. The temperature at 700 feet was 16°·08 R., and at 3,390 feet 34°·1 R. Plugs were then contrived which could be fixed tight in the bore at any depth with the thermometer between them, or could be fixed above the thermometer for observing at the bottom. Convection was thus prevented, and a difference of one or two degrees Réaumur was found in the temperatures at most of the depths; at 700 feet the temperature was now 17°·06 R., and at 3,390 feet 36°·15. We have thus direct evidence that convection had made the temperature at 3,390 feet 2°·05 R., or 4°·6 F. too low; and this, as Herr Dunker remarks, is an under-estimate of the error, inasmuch as convection had been exerting its equalising action for a long time, and its effect could not be completely destroyed in the comparatively short time that the plugs were in position. Again, as regards the effect of convection on the upper part of the bore, the temperature 11°·0 R. was observed at the depth of 100 feet in the principal bore when no plugs were employed, while a second bore only 100 feet deep in its immediate vicinity showed a temperature 9°·0 R. at the bottom. This is direct evidence that the water near the top of the great bore had been warmed 2° R. or $4\frac{1}{2}$° F. by convection.

Suggestions for observations in filled-up bores will be found in the eleventh report, but they have not yet taken a practical shape.

D. Questions affecting deductions from Observations.

1. In many instances the observations of temperature have been confined to considerable depths, and in order to deduce the mean rate of increase from the surface downwards it has been necessary to assume the mean temperature of the surface. To do this correctly is all the more difficult, because there seems to be a sensible difference between the mean temperature of the surface and that of the air a few feet above it.

In the third report some information on this point is given, based on observations of thermometers 22 inches deep at some of the stations of the Scottish Meteorological Society, and of thermometers 3 (French) feet

deep at Greenwich and at Edinburgh. These observations point to an excess of surface temperature above air temperature, ranging from half a degree to nearly two degrees, and having an average value of about one degree.

Dr. Schwartz, Professor of Physics in the Imperial School of Mines at Schemnitz, in sending his observations made in the mines at that place (X. 195), remarks on this point:—

'Observations in various localities show that in sandy soils the excess in question amounts, on the average, to about half a degree Centigrade. In this locality the surface is a compact rock, which is highly heated by the sun in summer, and is protected from radiation by a covering of snow in winter; and the conformation of the hills in the neighbourhood is such as to give protection against the prevailing winds. Hence the excess is probably greater here than in most places, and may fairly be assumed to be double the above average.'

Some excellent observations of underground temperature at small depths were made at the Botanic Gardens, Regent's Park, London, for the six years 1871–76, along with observations of air temperature, and have been reduced by Mr. Symons. They are at depths of 3, 6, 12, 24, and 48 inches beneath a surface of grass, and their joint mean derived from readings at 9 A.M. and 9 P.M. for the six years is 49·9, the mean for the 48-inch thermometer being 50·05. The mean air temperature derived in the same way from the readings of the dry-bulb thermometer is 49·6. Hence it appears that the excess of soil above air is in this case about 0°·4.

Quetelet's observations for three years at Brussels (p. 48 of his 'Mémoire') make the earth, at depths less than 1½ foot, colder than the air, and at greater depths warmer than the air.

Caldecott's observations for three years at Trevandrum, in India, make the ground at the depth of three feet warmer than the air by 5°·7 F.

Dr. Stapff, in his elaborate publications on the temperature of the St. Gothard tunnel, arrives at the conclusion that the mean temperature of the soil on the surface of the mountain above the tunnel is some degrees higher than that of the air, the excess increasing with the height of the surface and ranging from 2° or 3° C. near the ends of the tunnel to 5° or 6° C. in the neighbourhood of the central ridge.

Connected with this is the question—

2. Whether the mean annual temperature of the soil increases downwards from the surface itself, or whether, as is sometimes asserted, the increase only begins where annual range ceases to be sensible—say at a depth of 50 or 60 feet.

The general answer is obvious from the nature of conduction. Starting with the fact that temperature increases downwards at depths where the annual range is insensible, it follows that heat is travelling upwards, because heat will always pass from a hotter to a colder stratum. This heat must make its way to the surface and escape there. But it could not make its way to the surface unless the mean temperature diminished in approaching the surface; for if two superposed layers had the same mean temperature, just as much heat would pass from the upper to the lower as from the lower to the upper, and there would not be that excess of upward flow which is necessary to carry off the perennial supply from below.

This reasoning is rigorously true if the conductivity at a given depth

be independent of the temperature, and be the same all the year round. By 'conductivity' we are to understand the 'flux of heat' divided by the 'temperature-gradient;' where by the 'flux of heat' is meant the quantity of heat which flows in one second across unit area at the depth considered, and by the 'temperature-gradient' is meant the difference of temperature per foot of descent at the depth and time considered.

Convection of heat by the percolation of water is here to be regarded as included in conduction. If the conductivity as thus defined were the same all the year round, the increase of mean temperature per foot of depth would be independent of the annual range, and would be the same as if this range did not exist.

As a matter of fact, out of six stations at which first-class underground thermometers have been observed, five show an increase downwards and one a decrease. The following are the results obtained for the depths of 3, 12, and 24 French feet:—

	3 feet	12 feet	24 feet
Brussels, three years	51·85	53·69	53·71
Edinburgh (Craigleith), five years . .	45·88	45·92	46 07
,, (Gardens), five years . . .	46·13	46·76	.. 09
,, (Observatory), seventeen years .	46·27	46·92	47·18
Trevandrum, India, three years . . .	85·71	86·12	—
Greenwich, fourteen years	50·92	50 61	50·28

In calculating the mean temperature at 12 feet for Trevandrum, we have assumed the temperature of May, which is wanting, to be the same as that of April.

Omitting Trevandrum, and taking the mean values at 3 and 24 French feet, we find an increase of ·656 of a degree in 21 French feet, which is at the rate of 1° for 32 French, or about 34 English feet.

3. Another question which it has sometimes been necessary to discuss is the influence which the form of the surface exerts on the rate of increase of temperature with depth.

The surface itself is not in general isothermal, but its temperature is least where its elevation is greatest; the rate of decrease upwards or increase downwards being generally estimated at 1° F. for 300 feet. This is only about one-fifth of the average rate of increase downwards in the substance of the earth itself beneath a level surface. If the two rates were the same, the isotherms in the interior of a mountain would be horizontal, and the form of the surface would have no influence on the rate of increase of temperature with depth. The two extreme assumptions that the surface is an isotherm, and that the isotherms are horizontal, lie on opposite sides of the truth. The isotherms, where they meet the sides of the mountain, slope in the same direction as the sides of the mountain, but to a less degree. Probably the tangents of the two slopes are generally about as 3 to 4.

Further, if we draw a vertical line cutting two isotherms, the lower one must have less slope than the upper, because the elevations and depressions are smoothed off as the depth increases.

The practical inference is that the distance between the isotherms (in other words, the number of feet for 1° of increase), is greatest under mountain crests and ridges, and is least under bowl-shaped or trough-shaped hollows.

The observations in the Mont Cenis tunnel, and the much more complete observations made by Dr. Stapff in the St. Gothard tunnel, fully

bear out these predictions from theory. The discussion of the former occurs in the fourth report, p. 15.

As regards the St. Gothard tunnel, Dr. Stapff reports (XII. 41):—

'The mean rate of increase downwards in the whole length of the tunnel is ·02068 of a degree Centigrade per metre of depth, measured from the surface directly over. This is 1° F. for 88 feet. Where the surface is a steep ridge the increase is less rapid than this average; where the surface is a valley or plain the increase is more rapid.'

4. The question whether the rate of increase downwards is upon the whole the same at all depths, was raised by Professor Mohr in his comments upon the Sperenberg observations, and is discussed, so far as these observations bear upon it, in the 9th and 11th reports.

Against the Sperenberg observations, which upon the whole show a retardation of the rate of increase as we go deeper, may now be set the Dukinfield observations begun by Sir William Fairbairn (III.), and continued by Mr. Garside (XIII. 3). Taking Mr. Garside's observations, and assuming a surface temperature of 49°, the increase in the first $1{,}987\frac{1}{2}$ feet is at the rate of 1° in 79·5 feet; in the next 420 feet it is at the rate of 1° in 70 feet, and in the last $283\frac{1}{2}$ feet it is at the rate of 1° in $51\frac{1}{2}$ feet.

From a theoretical point of view, in places where there is no local generation of heat by chemical action, the case stands thus:—

The flow of heat upwards must be the same at all depths, and this flow is equal to the rate of increase downwards multiplied by the conductivity, using the word 'conductivity' (as above explained) in such a sense as to include convection. The rate of increase downwards must, therefore, be the same at all depths at which this conductivity is the same.

This reasoning applies to superposed strata at the same place, and assumes them to be sufficiently regular in their arrangement to ensure that the flow of heat shall be in parallel lines, not in converging or diverging lines.

5. If we have reason to believe that the flow of heat upwards is nearly the same at all places, then the above reasoning can also be applied approximately to the comparison of one place with another—that is to say, the rates of increase downwards in two masses of rock at two different places must be approximately in the inverse ratio of their conductivities. In the cooling of a heated sphere of heterogeneous composition, the rates of flow would at first be very unequal through different parts of the surface, being most rapid through those portions of the substance which conducted best; but these portions would thus be more rapidly drained of their heat than the other portions, and thus their rate of flow would fall off more rapidly than the rates of flow in the other portions. If the only differences in the material were differences of conductivity, we might on this account expect the outflow to be after a long time nearly the same at all parts of the surface. But when we come to consider differences of 'thermal capacity per unit volume,' it is clear that with equal values of 'diffusivity' that is of 'conductivity divided by thermal capacity of unit volume' in two places, say in two adjacent sectors of the globe, there would be the same distribution of temperatures in both, but not the same flow of heat, this latter being greatest in the sector in which the capacity and conductivity were greatest.

Where we find, as in Mr. Deacon's observations at Bootle, near Liverpool, and to a less marked degree in the observations of Sir William Fairbairn and Mr. Garside, near Manchester, an exceptionally slow rate

of increase, without exceptionally good conductivity, it is open to us to fall back on the explanation of exceptionally small thermal capacity per unit volume in the underlying region of the earth, perhaps at depths of from a few miles to a few hundred miles.

6. A question which was brought into consideration by Professor Hull, in connection with the great difference between the rate of increase at Dukinfield and that at Rosebridge (III. 33), is the effect of the dip of the strata upon the vertical conduction of heat. Laminated rocks conduct heat much better along the planes of lamination than at right angles to them. If k_1 denote the conductivity along, and k_2 the conductivity normal to the planes of lamination, and if these planes are inclined at an angle θ to the horizon, the number of feet per degree of increase downwards corresponding to a given rate of outflow through the surface, will be the same as if the flow were vertical with a vertical conductivity :—

$$k_1 \sin^2 \theta + k_2 \cos^2 \theta.$$

The following is the proof. Let the number of feet per degree of increase in the vertical direction be n, so that $\frac{1}{n}$ of a degree is the increase for a foot measured vertically. Then the increase for a foot measured in the direction of dip is $\frac{1}{n} \sin \theta$, and the increase for a foot measured perpendicular to the laminæ is $\frac{1}{n} \cos \theta$. The flow of heat in the direction of dip is, therefore, $\frac{1}{n} k_1 \sin \theta$, and the flow perpendicular to the laminæ $\frac{1}{n} k_2 \cos \theta$. Resolving each of these in the vertical direction, and adding, we get the vertical flow $\frac{1}{n} (k_1 \sin^2 \theta + k_2 \cos^2 \theta)$, which must be equal to the vertical rate of increase $\frac{1}{n}$ multiplied by the effective vertical conductivity.

Professor Herschel finds about 1·3 as the ratio of the two principal conductivities in Loch Rannoch flagstone, and 1·875 as the ratio in Festiniog slate.

The dip of the strata at Dukinfield is stated by Mr. Garside to be 15°, and we have $\sin^2 15° = \cdot 07$, $\cos^2 15° = \cdot 93$.

If we assume $k_1 = 1\cdot 3\, k_2$, as in the case of flagstone, we find for the effective vertical conductivity $k_2\, (\cdot 09 + \cdot 93) = 1\cdot 02\, k_2$, so that the number of feet per degree would only be increased by 2 per cent.

If we assume $k_1 = 1\cdot 875$, as in the case of slate, we find

$$k_2\, (\cdot 13 + \cdot 93) = 1\cdot 06\, k_2,$$

or the number of feet per degree would be 6 per cent. more than if the strata were horizontal.

It is not likely that the two conductivities in the strata at Dukinfield are so unequal as even in the case of flagstone, so that 2 per cent. is a high estimate of the effect of their dip on the vertical rate of increase so far as pure conduction is concerned. The effect of dip in promoting the percolation of water (III. 32) is a distinct consideration, but the workings

in the Dukinfield mines are so dry that this action does not seem to be important.[1]

E. WE NOW PROCEED TO A COMPARISON OF RESULTS. The localities at which definite results have been obtained may be thus classified:—

1. Metallic mines. 2. Coal mines. 3. Wells and wet borings. 4. Tunnels.

1. The mines at PRZIBRAM in Bohemia (VII. 15), with a depth of 1,900 feet, are in very quartzose rock, and give a very slow rate of increase, viz. 1°·1 in 135 feet. As all the shafts are in lofty hills, an allowance of $\frac{1}{15}$ may be made for convexity, leaving 1° F. in 126 feet. Quartz is found by Professor Herschel to have a conductivity of about ·0086.

The mines at SCHEMNITZ in Hungary (X. 194), with a depth of 1,368 feet, give an average rate of 1° F. in 74 feet, the rock being a green hornblende-andesite (in German, *Grünstein-Trachyt*), which is a compact, igneous, more or less vitreous rock. Professor Lebour estimates its conductivity as being probably nearly the same as that of Calton Hill trap-rock, which Professor Herschel found to be about ·0029.

The TALARGOCH lead mine (Flintshire) (XIII., XIV.), with its veins running across carboniferous limestone, has a depth of 1,041 feet, and gives in various parts rates varying from 1° in 47 feet to 1° in 113 feet. The average may be taken as 1° in 80 feet.

2. The results from coal mines are as follows, beginning with foreign mines:—

The mines of the Société Cocqueril at SERAING (Belgium) (VII. 17), with a depth of 1,657 feet, give an average rate of 1° F. in 50 feet. The rock is coal shale. Professor Herschel found for shale the low conductivity of ·0019.

The mines of ANZIN, in the north of France (IX. 210) with a depth of 658 feet, gave in the deepest shaft an increase of 1° in 47 feet.

ROSEBRIDGE COLLIERY, near Wigan (III.), with a depth of 2,445 feet, gave a mean rate of 1° in 54 feet.

The four following are in the East Manchester coalfield:—

ASTLEY PIT, Dukinfield (III., XIII.), with a depth of 2,700 feet, gave 1° in 72 ft.

ASHTON MOSS COLLIERY (XIV.), with a depth of 2,790 feet, gave 1° in 77 feet.

BREDBURY COLLIERY (XIV.), with a depth of 1,020 feet, gave 1° in 78·5 feet.

NOOK PIT (XIV.), with a depth of 1,050 feet, gave 1° in 79 feet.

DENTON COLLIERY, Lancashire (XV.), with a depth of 1,317 feet, gave an increase of 1° in about 77 feet.

SOUTH HETTON COLLIERY, Durham (V. 132, VI. 254), with a depth of 1,929 feet, including a borehole at bottom, gives very consistent observations at various depths, and an average rate of 1° in 57·5 feet.

BOLDON COLLIERY, between Newcastle and Sunderland (X. 197), with a depth of 1,514 feet, and excellent conditions of observation, gives an average rate of 1° in 49 feet.

WHITEHAVEN COLLIERY, Cumberland (XV.), in workings under the sea, with a depth of 1,250 feet beneath sea-level, or about 1,178 feet beneath the sea-bottom, gave an increase (from the sea-bottom) of about 1° in 45 feet.

KINGSWOOD COLLIERY, near Bristol (XII.), with a depth of 1,769 feet, and

[1] Though the workings are dry, there is a large quantity of water in the superincumbent strata. See Report XV.

remarkable consistency between observations at various points, gives 1° in 68 feet.

RADSTOCK COLLIERIES, near Bath (XIV.), with a depth of 1,000 feet, give a doubtful average of 1° in between 60 and 70 feet, the results in different parts being irregular. We have adopted 1° in 62 feet.

FOWLER'S COLLIERY, PONTYPRIDD, with a depth of 855 feet, gave, by one observation at the bottom compared with the known surface-temperature, a rate of 1° in 76 feet.

Professor Phillips' observations in MONKWEARMOUTH COLLIERY, published in 'Phil. Mag.' for December 1834, showed a temperature of 71°·2 in a hole bored in the floor of a recently exposed part at the depth of 1,584 feet. The surface of the ground is 87 feet above high water, and the mean temperature of the air is assumed by Professor Phillips to be 47°·6. If, as usual, we add 1° to get the soil temperature, instead of assuming, as Professor Phillips does, that the temperature 100 feet deep is identical with the air temperature at the surface, we obtain a rate of increase of 1° in 70 feet.

3. The following are the most trustworthy results from wells and borings:—

The SPERENBERG bore, near Berlin (IX. 204), in rock salt, with a depth of 3,492 English feet, to the deepest reliable observation, gave an average of 1° in 51·5 feet. This result is entitled to special weight, not only on account of the great depth, but also on account of the powerful means employed to exclude convection.

Rock salt, according to Professor Herschel, has the very high conductivity ·0113.

Three artesian wells in the chalk of the PARIS BASIN gave the following results (IV. 24):—

St. André, depth of observation .	830 ft.	. rate	1° in 56·4 ft.
Grenelle	1,312 „	. „	1° in 56 9 „
Military School	568 „	. „	1° in 56·2 „

The great well of LA CHAPELLE, in the same basin, is not yet finished, and a very great change in its indications may be expected when it strikes the strong springs which it is intended to bring to the surface. Up to the present time the deepest observation has been at 2,165 feet, and this, by comparison with the known temperature in the artificial caves under the Paris Observatory, gives a rate of 1° in 90·5 feet, which is probably much slower than the truth, by reason of convection. The temperature at 328 feet compared with that at 2,165 feet, gives 1° in 111 feet, this result being affected by convection at both ends.

An artesian well at ST. PETERSBURG (IV. 22), in the Lower Silurian strata, with a depth of 656 feet, gives about 1° in 44 feet.

A well sunk at YAKOUTSK, in Siberia (IV. 22), to the depth of 540 feet, disclosed the fact that the ground was permanently frozen to this depth, and probably to the depth of 700 feet. The rate of increase of temperature was 1° in 52 feet.

Of the English wells in which observations have been taken, the most important is that at KENTISH TOWN (II., III., IV.), in which Mr. G. J. Symons, F.R.S., has taken observations to the depth of 1,100 feet. The temperatures at different depths form a smooth series, and have been confirmed by observations repeated at long intervals. The only question that can arise as to the accuracy of the results is the possibility of their being affected by convection.

The well is 8 feet in diameter, with brickwork to the depth of 540 feet, and this part of it is traversed by an iron tube 8 inches in diameter, which is continued to the depth of more than 1,300 feet from the surface. The tube is choked with mud to the depth of about 1,080 feet, so that the deepest observations were taken under 20 feet of mud. The temperature at 1,100 feet was 69°·9, and by combining this with the surface temperature of 49°·9 observed at the Botanic Gardens, Regent's Park, we obtain a rate of 1° in 55 feet. These data would give at 250 feet a calculated temperature of 54·5, whereas the temperature actually observed at this depth was 56·1, or 1°·6 higher; the temperature at 300 feet and at 350 feet being also 56·1. This seems to indicate convection, but it can be accounted for by convection in the 8-foot well which surrounds the tube, and does not imply convection currents within the tube. Convection currents are much more easily formed in water columns of large diameter than in small ones, and the 20 feet of mud at the bottom give some security against convection at the deepest point of observation. It is important to remark that the increase from 1,050 to 1,100 feet is rather less than the average, instead of being decidedly greater, as it would be if there were convection above, but not in, the mud. The rate of 1° in 55 feet may therefore be adopted as correct.

Mr. Symons also made numerous observations in this well (VI., IX., XII.) to determine whether the temperature at the depth of 1,000 feet remained exactly the same at all seasons and from year to year. The result was that the changes, if any, were so small as not to be distinguishable from the necessary errors of observation. The research was finally abandoned, because the gradual silting up of the well, which was found to be going on, would itself be competent to account for any small secular change that might have been detected by further observation.

The strata, consisting of tertiary strata, chalk (586 feet thick), upper greensand and gault, are given in detail on the last page of the third report.

The Kentish Town temperature at the depth of 400 feet (58°) is confirmed by observations in Mr. Sich's well at Chiswick (VIII. 159), which is 395 feet deep, and has a temperature varying from 58° to 57°·5.

The Bootle well, belonging to the Liverpool Waterworks, is 1,302 feet deep, and the observations were taken in it during the sinking (XI., XII.) The diameter of the bore is 24 inches, and convection might have been suspected but for the circumstance that there was a gradual upward flow of water from the bottom, which escaped from the upper part of the well by percolation to an underground reservoir near at hand. This would check the tendency to downflow of colder water from the top; and as the observations of temperature were always made at the bottom, they would thus be protected against convective disturbance.

The temperature at 226 feet was 52°, at 750 feet 56°, at 1,302 feet 59°, giving by comparison of the first and last of these a mean rate of 1° in 154 feet. The circumstance that the boring ceased for six weeks at the depth of 1,004 feet, and the temperature fell during this interval from 58°·1, to 57°·0, would seem to indicate an elevation of 1° due to the heat generated by the boring tool. An assumed surface temperature of 49° (only 0°·9 lower than that of the Botanic Gardens in London), would give by comparison with 57°, at 1,004 feet, a rate of 1° in 125½ feet, and by comparison with 59°, at 1,302 feet, a rate of 1° in 130 feet, which last may be adopted as the best determination. The rock consists of the

pebble beds of the Bunter or Lower Trias, and the boring was executed at the rate of nearly 100 feet per month.

The boring at Swinderby, near SCARLE (Lincoln), in search of coal (VIII., IX.), was carried to a depth of 2,000 feet, with a diameter at the lower part of only $3\frac{1}{8}$ inches—a circumstance favourable to accuracy, both as impeding convection and as promoting the rapid escape of the heat of boring. The temperature at the bottom was 79°, the water having been undisturbed for a month, and this by comparison with an assumed surface temperature of 50° gives a rate of 1° in 69 feet.

The rocks are Lower Lias, New Red Marl (569 feet thick), New Red Sandstone (790 feet thick), Red Marl, and earthy Limestone.

The following results have been obtained from shallow borings. The first three were made under Sir William Thomson's direction, with a thermometer which could be read by estimation to hundredths of a degree:—

BLYTHSWOOD bore, near Glasgow (I.), with a depth of 347 feet, gave a very regular increase of 1° in 50 feet.

KIRKLAND NEUK bore, in the immediate vicinity of the above (II.), gave consistent observations at different seasons of the year from 180 feet to the bottom (354 feet), the rate being 1° in 53 feet. This bore passed through coal which had been 'very much burned or charred.'

SOUTH BALGRAY bore, near Glasgow, and north of the Clyde, with an available depth of 525 feet, gave, by comparing the temperature at the bottom with that at 60 feet, a rate of 1° in 41 feet.

Shale extends continuously from 390 to 450 feet from the surface, and the increase in these 60 feet of shale was 2°·02, which is at the rate of 1° in 30 feet. This rapid increase agrees with the fact that shale has very low conductivity, averaging ·0019 in Professor Herschel's experiments.

The only small bore remaining to be mentioned is that at MANEGAON, in India (X. 198), which had 310 feet available, and gave by comparing the temperature at this depth with that at 60 feet a rate of 1° in 68 feet. The rocks consist of fine softish sandstones and hard silty clays, the dip being 10°.

The following results, obtained from observations at the bottom of shafts with only a small depth of water, are not altogether without value, though the circumstances are not favourable to accuracy:—

Two shafts of salt mines near CARRICKFERGUS (Ireland) (II. 12, 13), with depths of 570 feet and 770 feet, gave by comparison with an assumed surface temperature of 48° rates of 1° in 40 feet and 1° in 43 feet. The soil in both cases was yellow clay, a substance for which Professor Herschel finds the low conductivity of ·0025.

In a 'sump' at the bottom of Slitt mine, in the ALLENHEADS lead mines, Weardale (Northumberland) (IV.), at 660 feet from the surface, the temperature 65°·0 was found, which, by comparison with the surface temperature, 45°·3, assumed by the observer (Mr. Burns, of H.M. Geological Survey), being a degree higher than the observed air temperature in the neighbourhood, gives a rate of 1° in 34 feet. The strata consist of alternate beds of sandstone and shale, with a few beds of limestone, 158 feet of basalt, and 55 feet of fluor spar.

4. **Tunnels.**—The MONT CENIS tunnel (IV. 15), which is about 7 miles long, is at a depth of exactly a mile (5,280 feet) beneath the crest of Mont Fréjus overhead. This was the warmest part of the tunnel, and had a

temperature of 85°·1 F. The mean air temperature at the crest overhead was calculated by the engineer of the tunnel, M. Giordano, by interpolating between the known temperature of the pass of San Theodule and that of the city of Turin, the former being 430 metres higher, and the latter 2,650 metres lower, than the point in question. It is thus calculated to be − 2°·6 C. or 27°·3 F. If, according to our usual rule, we assume the ground to be 1° warmer than the air, we have 28°·3 to compare with 85°·1. This gives a rate of 1° in 93 feet; but, inasmuch as the convexity of the surface increases the distance between the isotherms, a correction will be necessary before we can fairly compare this result with rates under level ground. As a rough estimate we may take $\frac{7}{8}$ of 93, and adopt 1° in 79 feet as the corrected result.

'The rocks on which the observations have been made are absolutely the same, geologically and otherwise, from the entrance to the tunnel, on the Italian side, for a distance of nearly 10,000 yards. They are not faulted to any extent, though highly inclined, contorted, and subjected to slight slips and slides. They consist, to a very large extent indeed, of silicates, chiefly of alumina, and the small quantity of lime they contain is a crystalline carbonate.'

The St. Gothard Tunnel (VIII., XI., XII.), which has a length of about 9 miles, has been subjected to much more minute observation, a skilled geologist, Dr. Stapff, having, under Government direction, devoted his whole time to investigating its geology and physics. He not only observed the temperature of the rock in the tunnel at very numerous points, but also determined, by observations of springs, the mean temperatures of the surface of the mountain at various points, and compared these with an empirical formula for air temperature deduced from the known mean temperatures of the air at Göschenen, Andermatt, Airolo, and the Hospice of St. Bernard. He infers from his comparisons a considerable excess of soil above air temperature, increasing from 2° C. at the ends of the tunnel to 6° C. at the crest of the mountain over the centre of the tunnel. The highest temperature of the rocks in the tunnel was at this central part, and was about 30°·6 C. or 87° F. The soil temperature at the crest above it was about − 0°·6 C. or 31° F., giving a difference of 56° F. The height of the crest above sea-level was about 2,850 m., and that of the tunnel at this part 1,150 m., giving a difference of 1,700 m. or 5,578 feet. The rate of increase here is, therefore, about 1° F. in 100 feet; and if we apply the same correction for convexity as in the case of the Mont Cenis tunnel, this will be reduced to about 1° F. in 87 feet, as the equivalent rate under a level surface. From combining his observations in all parts of the tunnel, through the medium of empirical formulæ, Dr. Stapff deduces an average rate of 1° F. for every 88 feet measured from the surface directly overhead. Where the surface is a steep ridge, the increase was less rapid than this average; where the surface was a valley or plain, the increase was more rapid. As this average merely applies to the actual temperatures, the application of a correction for the general convexity of the surface would give a more rapid rate. If we bring the isotherms nearer by one part in 15, which seems a fair assumption, we shall obtain a rate of 1° F. in 82 feet.

Collecting together the foregoing results, and arranging them mainly in the order of their rates of increase, but also with some reference to locality, we have the following list:—

	Depth feet	Feet for 1° F.
Bootle waterworks (Liverpool)	1,392	130
Przibram mines (Bohemia)	1,900	126
St. Gothard tunnel	5,578	82
Mont Cenis tunnel	5,280	79
Talargoch lead mine (Flint)	1,041	80
Nook Pit, colliery (East Manchester coalfield)	1,050	79
Bredbury „ (East Manchester coalfield)	1,020	78½
Ashton Moss „ (East Manchester coalfield)	2,790	77
Denton „ (East Manchester coalfield)	1,317	77
Astley Pit, Dukinfield (East Manchester coalfield)	2,700	72
Schemnitz mines (Hungary)	1,368	74
Scarle boring (Lincoln)	2,000	69
Manegaon boring (India)	310	68
Pontypridd colliery (S. Wales)	855	76
Kingswood colliery (Bristol)	1,769	68
Radstock „ (Bath)	620	62
Paris artesian well, Grenelle	1,312	57
„ „ St. André	830	56
„ „ Military School	568	56
London „ Kentish Town	1,100	55
Rosebridge colliery (Wigan)	2,445	54
Yakoutsk, frozen ground (Siberia)	540	52
Sperenberg, boring in salt (Berlin)	3,492	51½
Seraing collieries (Belgium)	1,657	50
Monkwearmouth collieries (Durham)	1,584	70
South Hetton „ „	1,929	57½
Boldon „ „	1,514	49
Whitehaven „ (Cumberland)	1,250	45
Kirkland Neuk bore (Glasgow)	354	53
Blythswood „ „	347	50
South Balgray „ „	525	41
Anzin collieries (North of France)	658	47
St. Petersburg, well (Russia)	656	44
Carrickfergus, shaft of salt mine (Ireland)	770	43
„ „ „	570	40
Slitt mine, Weardale (Northumberland)	660	34

The depth stated is, in each case, that of the deepest observation that has been utilised.

F. In deducing a mean from these very various results, it is better to operate not upon the number of feet per degree, but upon its reciprocal —the increase of temperature per foot. Assigning to the results in the foregoing list weights proportional to the depths, the mean increase of temperature per foot is found to be ·01563, or about $\frac{1}{64}$ of a degree per foot—that is, 1° F. in 64 feet.

It would be more just to assign greater weight to those single results which represent a large district or an extensive group of mines, especially where the data are known to be very accurate. Doubling the weights above assigned to Przibram, St. Gothard, Mont Cenis, Schemnitz, Kentish Town, Rosebridge, and Seraing, and quadrupling that assigned to Sperenberg, no material difference is made in the result. The mean still comes out 1° F. in 64 feet, or more exactly ·01566 of a degree per foot.

This is a slower rate than has been generally assumed, but it has been fairly deduced from the evidence contained in the Committee's Reports; and there is no reason to throw doubt on the results in the upper portion of the above list more than on those in its lower portion. Any error that can reasonably be attributed to the data used in the calculations for the

St. Gothard tunnel and for the numerous deep mines of the East Manchester coalfield, will have only a trifling effect on the rates of increase assigned to these localities.

To obtain an approximation to the rate at which heat escapes annually from the earth, we will first reduce the above rate of increase ·01566 to Centigrade degrees per centimetre of depth. For this purpose we must multiply by ·0182, giving ·000285.

To calculate the rate of escape of heat, this must be multiplied by the conductivity.

The most certain determinations yet made of the conductivity of a portion of the earth's substance are those deduced by Sir William Thomson by an indirect method, involving observations of underground thermometers at three stations at Edinburgh, combined with laboratory measurements of the specific heats and densities of the rocks in which the thermometers were planted. The specific heats were determined by Regnault, and the densities by Forbes. Specific heats and densities can be determined with great accuracy in the laboratory, but the direct determination of conductivity in the laboratory is exceedingly difficult, it being almost impossible to avoid sources of error which make the conductivity appear less than it really is.

Professor Herschel, in conjunction with a Committee of the British Association, has made a very extensive and valuable series of direct measurements of the conductivities of a great variety of rocks, and has given additional certainty to his results by selecting as two of the subjects of his experiments the Calton Hill trap and Craigleith sandstone, to which Sir William Thomson's determinations apply. Comparison shows that Professor Herschel's results for these two substances, as given in the fifth Report of the Conductivity Committee (1878), must be multiplied by about 1·4 to make them agree with Sir William Thomson's.[1]

The following list, condensed from that Report, will be useful for our purpose :—

Mean Conductivities in C.G.S. measure, from Professor Herschel's Determinations.

Rock salt	·0113	Clay slate	·0027
Quartz	·0086	Clay	·0025
Sandstone	·0060	Chalk	·0026
Flagstone	·0046	Firestone	·0021
Slate	·0040	Shale	·0019
Granite	·0053	Sand, dry	·0009
Limestone	·0052	„ saturated	·0070
Serpentine	·0044	Coal	·0008
Trap	·0038	Pumice	·0006

The mean of these 18 values is ·00413, which, if multiplied by the correcting factor 1·4 above mentioned, gives ·0058.

Sir William Thomson's three determinations were :—

Trap rock of Calton Hill	·00415
Sand of Experimental Garden	·00262
Sandstone of Craigleith Quarry	·01068

These give a mean of ·00582, which is sensibly the same as the above.

[1] The sixth Report of the Conductivity Committee states that a mistake was made in the factor employed for reducing the results to C. G. S., and that the results as given in the fifth Report require to be increased by one-eighth part of their respective amounts.

Adopting ·0058 as the mean conductivity of the outer crust of the earth, we have

$$\cdot 0058 \times \cdot 000285 = 16330 \times 10^{-10}$$

as the flow of heat in a second across a square centimetre. Multiplying by the number of seconds in a year, which is approximately $31\frac{1}{2}$ millions, we have

$$1633 \times 315 \times 10^{-4} = 41\cdot 4$$

This then is our estimate of the average number of gramme-degrees of heat that escape annually through each square centimetre of a horizontal section of the earth's substance.

Report of the Committee, consisting of Professor SCHUSTER (*Secretary*), Sir WILLIAM THOMSON, Professor H. E. ROSCOE, Professor A. S. HERSCHEL, Captain W. DE W. ABNEY, Mr. R. H. SCOTT, *and* Dr. J. H. GLADSTONE, *appointed for the purpose of investigating the practicability of collecting and identifying Meteoric Dust, and of considering the question of undertaking regular observations in various localities.*

1. IN their first Report the Committee confined itself to giving a short abstract of some of the work which had hitherto been done to clear up the important question with which they are concerned. Since that time the previous literature has been more thoroughly studied, and a microscopic investigation of different specimens of magnetic dust derived from various sources has been undertaken.

A good deal of the literature confines itself to the dust-falls which are frequently observed in the Atlantic, in the southern parts of Italy, and sometimes in the Red Sea. These dust-falls were at one time supposed to be of meteoric origin, but it has now been conclusively proved that the dust has its origin in the sandy deserts of Northern Africa, whence it is carried by the winds often through considerable distances; the grosser particles falling down first, so that ultimately only the finest remain in suspension. With these dust-falls we are not directly concerned, but we wish to point out that because as a whole they are proved to be of terrestrial origin it does not follow that everything they contain is terrestrial. Granting for a moment that meteoric dust exists, that dust would accumulate in the desert as well as anywhere else, we should expect that some of the magnetic particles carried by these dust-storms would show the same peculiarities which, in other cases, have led to the supposition of their meteoric origin. Such indeed is the case; but before entering into details on this point we must give a short account of the very clear line of argument by means of which Tissandier has to most minds established the existence and general prevalence of meteoric dust.

Tissandier has fully discussed the question in his interesting little book 'Les poussières de l'air,'[1] and has described the result of the microscopic examination of the dust gradually settled down in dry weather, or

[1] Paris, Gauthier Villars, 1877.

precipitated by rain and snow. We are concerned here chiefly with the magnetic particles contained in this dust. These particles are of various shapes, but the most remarkable form is perfectly spherical, which at once conveys the obvious information that the particles at one time must have been in a state of fusion. These spherules have been found in the snows on the slopes of Mont Blanc, at a height of nearly 9,000 feet in the sediment of rain collected at the Observatory of Sainte-Marie-du-Mont, and in the dust collected at different elevated positions. There are other particles, not spherical but of equally characteristic forms, which generally accompany these spherules, and some of these shapes we find in the iron dust extracted by Nordenskjöld from the sand of the polar regions. If we confine ourselves, however, at present to the spherical particles, and accept the conclusion that they have been in a state of fusion, we are practically reduced to three alternatives. The particles may be of volcanic origin, they may have been fused in our terrestrial fires, or they may be meteoric. All the volcanic dust which the writer has had at his disposal was carefully examined under the microscope, and its appearance was found to be altogether different from the supposed meteoric dust. Such also seems to be the conclusion arrived at by Tissandier. No iron spherules have, as far as I know, been found in volcanic dust.

The smoke issuing from the chimneys of our manufacturing towns can and does contain iron particles similar in appearance to those to which Tissandier ascribes a meteoric origin. That some of these particles are found very far from any terrestrial sources which can produce them would not perhaps tell conclusively against their terrestrial origin, but chemical analysis seems to settle the point. The iron particles issuing from our chimneys contain neither nickel nor cobalt; while these metals were found by Tissandier to exist in the microscopic magnetic particles found in rain-water collected at the Observatory of Sainte-Marie-du-Mont. We are, therefore, driven to ascribe a cosmic origin to these particles.

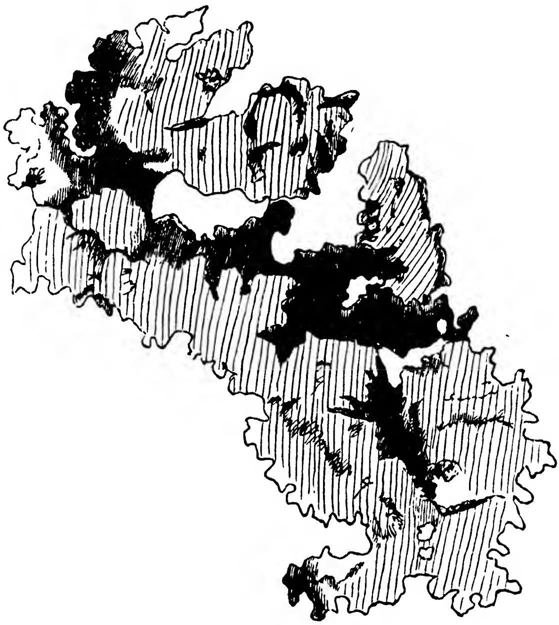
2. The author of this Report has, during the last year, made a few microscopic investigations of small iron particles found in different places. He has obtained in the first place sand collected from the desert in the neighbourhood of the Great Pyramids. This sand contains an appreciable quantity of magnetic particles (1 part in 144,000). Examined by the microscope the greater part of these particles were found to be angular in shape, and there can be no doubt that they form an integral part of the sand, and are due to the *débris* of magnetic rocks. But here and there we find perfect spheres of iron exactly like those described by Tissandier and about the same diameter, that is, 0·2 to 0·1 millimetre; some of them are even larger. Fig. 1 shows some of these spherules as seen under the microscope. Figs. 2 and 3 give another form of frequent occurrence.

FIG. 1.—Globular Pieces of Iron as seen under the microscope (objective ⅛ inch), March 16, 1882. Specimen of Sand collected near the Pyramids in the Desert of Sahara.

The greater part of these latter particles are metallic iron, as is shown by the deposition of copper on them when a drop of a solution of sulphate of copper is added. In fig. 2 all the light parts represent the metallic iron. The total quantity of this metallic iron must, however, have been small, for it could not be traced by chemical analysis.

Mr. J. B. B. Hennessey was kind enough to forward me some sand which was collected at his request, and with proper precautions specified by him, in desert of Rájputáná, in lat. N. 27° 40′ 25″, long. E. 72° 43′ 39″; the nearest village being full 13 miles distant. The examination of this sand has not as yet been completed, but at present no spherical

FIG. 2.—Iron Particle in Sahara Sand. The light parts are metallic. Enlargement, 100 : 1.



particles have been found, nor is there any appearance of metallic iron. But the sand contains a comparatively large quantity of magnetic oxide (0·1 per cent.). This magnetic oxide, which is of undoubted terrestrial origin, will naturally hide any traces of meteoric dust, which could only form a small percentage of the total magnetic part.

FIG. 3.—Metallic Iron in Sahara Sand, 100 : 1.

Similar negative results were obtained with some specimens of mud collected on the banks of the Nile near the village of Sohag (lat. 26° 33′, long. E. 2^h 07^m), on the occasion of the last total solar eclipse. Here also a very large quantity of *débris* from magnetic rocks was found in the mud, hiding any meteoric particles which might have been there.

3. We may approach the question from yet another point of view. A shooting star is not an uncommon phenomenon, and on certain nights in the year we often find them counted by hundreds. Each of these meteors will leave traces behind in our atmosphere, for it seems hardly possible that when white hot, owing to the friction with our atmosphere, part of this surface should not fuse and be left behind in a finely divided state.

In addition to this we also hear of larger meteors passing through the air more slowly, but leaving behind trains of luminous clouds remaining visible for a considerable length of time. What becomes of all this matter, and how should we expect it to look after it has settled down on the surface of our earth? Tissandier has examined microscopically some powder which he has detached from the surface of a meteoric stone found in Bohemia, and it was found to resemble in appearance the magnetic particles found in different places to which he had attributed a meteoric origin.

4. An interesting question arises in connection with the iron particles which are found in the metallic state in the sand of the desert of Sahara and in other localities. How did they escape oxidation, either when first detached from the molten mass of the meteoric dust, or subsequently. Several explanations of this fact may be offered. If the particles are really meteoric they would contain a considerable proportion of nickel, and such iron is able to resist oxidation to a high degree. But the presence of nickel would not prevent their transformation into magnetic oxide when red hot, as they must have been when they separated from the meteor. I wish, however, to point out that possibly, and even probably, the separation has taken place at a height at which the atmosphere contains only comparatively small quantities of oxygen. It is known by the laws of diffusion that, assuming everything to be in a state of equilibrium, each gas will form an atmosphere round the terrestrial globe independently of any other gas which may be present. It follows that at great heights the lighter gases will be present in preponderating proportions, as compared with the lower regions. Calculating, for instance, the proportion of oxygen which we should expect at different heights if the temperature is the same throughout, we find as follows:—

At a height of	0	kilometres	21	per cent. of	oxygen.
,,	,, 5	,,	19·5	,,	,,
,,	,, 10	,,	18	,,	,,
,,	,, 100	,,	4·2	,,	,,
,,	,, 150	,,	2	,,	,,
,,	,, 200	,,	0·8	,,	,,

Convection currents would, no doubt, especially within the lower regions, tend to equalise the difference between the higher and lower parts, but the fact must remain that, at a height at which luminous meteors have been seen luminous, the oxygen can only form a small fraction of the atmosphere. But matters become still more striking if we consider that probably some other and lighter gas is present in addition to the oxygen and nitrogen.

Spectroscopic observations of the Aurora Borealis show the presence of a green line which no one has as yet obtained from any known constituent of the atmosphere. I have myself observed nitrogen, and oxygen and some of the carbon compounds, under so many different conditions that I am fully convinced that the line is not due to them, but must be due to the presence of some unknown gaseous body. As we cannot detect it near the surface of the earth, this gas must be very light. Supposing, for the sake of argument, that it is as dense as hydrogen, and that at the surface of the earth its quantity per cubic centimetre is only the millionth part of the oxygen present in the same space, it would certainly escape all our methods of analysis. But from these suppositions we can calculate that,

at a height of 200 kilometres, it must exceed the oxygen in proportion of 170,000 to 1—that is to say, at that height the atmosphere would practically contain no oxygen. If the gas is less dense than hydrogen this proportion would still further be increased. Even those who do not feel inclined to assume the presence of an unknown gas will not deny the possibility that free hydrogen may be present in our atmosphere in such small quantities as we have assumed. Electric discharges which are constantly going on partially decompose the aqueous vapour of the atmosphere, and some of it will escape recombination. If then free hydrogen exists even in quantities only which are very small on the surface of the earth, it may be in preponderating proportion in the upper regions.

After having considered the above explanation of the fact that some of the meteoric iron may be in the metallic state, I have made a few experiments which tend to show that iron dust may separate from a red-hot meteor even in atmosphere containing considerable quantities of oxygen, and yet escape oxidation. Tissandier has shown how by burning an iron wire in oxygen we may often obtain iron spherules of exactly the same nature as those floating in our atmosphere. I have obtained similar spherules by using an iron file as one pole of a dynamo-machine, and passing the file over a copper wire connected with the other pole. The sparks flying off in all directions are found to consist chiefly of iron globules like those to which Tissandier ascribes a meteoric origin; but in addition we have small spongy masses which are metallic, and present exactly the same appearance as the metallic iron found in the Saharah desert. The most remarkable fact, however, is this, that we find even a few globules of iron which are metallic. These globules must have been in a state of fusion, and yet they did not oxidise at the contact of the air, no doubt owing to the fact that a large number of particles used up the free oxygen of the air in the neighbourhood of the few particles which thus escaped.

5. The question of meteoric dust suggests another interesting reflection. Mr. Aitken has recently shown how a condensation of aqueous vapour only takes place round a nucleus of solid matter. It is no doubt one of the most interesting questions to decide what forms in different localities the most common nucleus for fogs, rain, snow, or hail. We conclude this Report by mentioning the very suggestive fact, that Nordenskjöld has found iron particles as a nucleus to hailstones at Stockholm, and that observations of the same kind have been made in Spain, where also hailstones were found to contain iron particles as a nucleus. Other observations of the same nature seem to exist.

There is every reason to believe that the blue colour of the sky is due to minute particles scattering the light. These particles must be much more minute than any which the Committee has at present investigated; they must, in fact, be beyond the limits of microscopic power. It might, however, be possible ultimately to find out the nature of these small particles. It is interesting to record the observation made by the author of this Report, that in the valleys of the Himalayas which are cultivated, the colour of the sky is much whiter than in the valleys which are barren and devoid of any vegetation.

Second Report of the Committee, consisting of Mr. G. H. DARWIN, Professor Sir WILLIAM THOMSON, Professor TAIT, Professor GRANT, Dr. SIEMENS, Professor PURSER, Professor G. FORBES, *and* Mr. HORACE DARWIN, *appointed for the Measurement of the Lunar Disturbance of Gravity. Written by* Mr. G. H. DARWIN.

Shortly after the meeting of the British Association last year (1881), the instrument with which my brother and I were experimenting at the Cavendish Laboratory, at Cambridge, broke down, through the snapping of the wire which supported the pendulum. A succession of unforeseen circumstances have prevented us, up to the present time, from resuming our experiments.

The body of the present Report, therefore, will merely contain an account of such observations by other observers as have come to our knowledge within the past year, and it must be taken as supplementary to the second part of the Report for 1881. The Appendix, however, contains certain theoretical investigations, which appear to me to throw doubt on the utility of very minute gravitational observations.

The readers of the Report for 1881 will remember that, in the course of our experiments, we were led away from the primary object of the Committee, namely the measurement of the Lunar Disturbance of Gravity, and found ourselves compelled to investigate the slower oscillations of the soil.

It would be beyond the scope of the present Report to enter on the literature of seismology. But, the slower changes in the vertical having been found to be intimately connected with earthquakes, it would not have been possible, even if desirable, to eliminate all reference to seismology from the present Report.

The papers which are quoted below present evidence of a very miscellaneous character, and therefore this Report must necessarily be rather disjointed. It has seemed best in our account of work done rather to classify together the observers than the subjects. This rule will, however, be occasionally departed from, when it may seem desirable to do so.

The interesting researches in this field made during the last ten years by the Italians, are, I believe, but little known in this country, and as the accounts of their investigations are not easily accessible (there being, for example, no copy of the 'Bulletino' referred to below at Cambridge), it will be well to give a tolerably full account of the results attained. I have myself only seen the 'Transactions' for four years.

The great extension which these investigations have attained in Italy has been no doubt due to the fact of the presence of active volcanos and of frequent sensible earthquakes in that country. But it is probable that many of the same phenomena occur in all countries.

In 1874 the publication of the 'Bulletino del Vulcanismo Italiano' was commenced at Rome under the editorship of Professor S. M. de Rossi, of Rome.[1] As the title of this publication shows, it is principally occupied with accounts of earthquakes, but the extracts made will refer almost entirely to the slower oscillations of level.

[1] I am compelled to make this abstract from manuscript notes; but my papers having become somewhat disarranged, I am not absolutely certain, in one or two places, of the year to which the observations refer.

I learn from the 'Bulletino' that in 1873 Professor Timoteo Bertelli, of Florence, had published an historical account of small spontaneous movements of the pendulum, observed since the seventeenth century up to that time.[1]

In 1874 (Anno 1 of the 'Bulletino') Rossi draws attention to the fact that there are periods lasting from a few days to a week or more, in which the soil is in incessant movement, followed by a comparative cessation of such movement. This he calls a 'seismic period.' In the midst or at the end of a seismic period there is frequently a sensible earthquake.

At page 51 he remarks, in a review of some observations of Professor Pietro Monte (Director of the Observatory of Leghorn), that he was led to suspect that the crust of the earth is in continuous and slow movement during the seismic period, and that this movement is influenced by variations of barometric pressure. This suspicion was, he says, confirmed by finding, in his observations of a pendulum at Rocca di Papa (of which we shall speak again below), that during the seismic period the excursions of the pendulum were mostly in the S.W. and N.E. azimuth. This is perpendicular to the volcanic fracture, which runs towards the Alban lake and the sea. The lips of the fracture rise and fall, and there result two sets of waves along and perpendicular to the fracture. In an earthquake these waves are propagated with great velocity (the phenomenon being in fact dynamical), but during the seismic period the same class of changes takes place slowly. This view accords with observations at Velletri made by Professor D. G. Galli.

With regard to the influence of barometric pressure Rossi elsewhere quotes M. Poey (October 15, 1857 ?) as having attributed the deviations of the vertical to this cause, and remarks:—

'Although he (Poey) gave too much weight to the baro-seismic action of large variations of atmospheric pressure, yet after very numerous observations made by me in these last three years (I suppose 1871–4), I can affirm that no marked barometric depression has occurred without having been immediately preceded, accompanied, or followed by marked micro-seismic movements; but besides these there are other irregular, often considerable and instantaneous movements, which occur under high pressure. To distinguish them, I have called the first *baro-seismic*, and the second *vulcano-seismic*, movements.' The reader will find a theoretical investigation on this subject in the Appendix to the present Report.

Rossi states (page 118, Anno 1 ?) that whilst Etna was in a condition of activity his pendulums at Rocca di Papa were extraordinarily agitated at the beginning of each barometric storm.

At page 90 of the second year are given graphical illustrations of the simultaneous deflections of pendulums at Rome, Rocca di Papa, Florence, Leghorn, and Bologna. There is some appearance of concordance between them, and this shows that the agitations sometimes affect considerable tracts of land, but that the minor deflections are purely local phenomena.

M. d'Abbadie, in presenting a memoir on micro-seismic movements by Father Bertelli to the French Academy, relates ('Comptes Rendus,' 1875, vol. 81, p. 297) the following experiment made by Count Malvasia, as proving the independence of the disturbances of the pendulum from the tremors produced by traffic. Two batteries of artillery were marching

[1] *Bulletino Boncampagni*, t. vi. Gennaio, 1873. Reprinted Via Lata, No. 2114, Rome.

through Bologna, and it was arranged that at 30 meters from the Palazzo Malvasia they should break into a trot. The pendulum, situated only 6 meters from the street, was observed to be unaffected by this, and continued its oscillations in the E.W. azimuth. A pool of mercury was violently agitated, and it was concluded that the motion communicated to the ground by the artillery was exclusively vertical.

At page 5 of the 'Bulletino' for 1876 (January to May), Rossi writes a 'Guida pratica per le osservazioni sismiche.' This article contains a description of the instruments which have been used by the Italian observers.

Bertelli used a pendulum protected from the air, with a microscope and micrometer for evaluating the oscillations. The upper part of the support of the pendulum consisted of a spiral spring, so that vertical movements of the ground could be recorded. This instrument he calls a tromo-seismometer.

Professor Egidi, of Anagni, proposed to use the reflection from mercury. The object observed was to be a mark fixed on a wall, and the reflected image of the mark was to be observed with a telescope. The deviation of the vertical was to be evaluated by noting the amount of movement required to bring the cross-wires of the telescope on to the mark. This instrument has not, I think, the advantages ot M. d'Abbadie's, because the light was incident at about 45° on the mercury, and thus the mark and telescope were remote from one another; whereas in the arrangement of M. d'Abbadie the mark and microscope are close together, and only a micrometer wire in the microscope is movable.

Cavalleri used ten pendulums of graduated length, and found that sometimes one of the pendulums was agitated and sometimes another. Rossi observed the same with his pendulums at Rocca di Papa. It thus appears that the free period of oscillation of the pendulum is a disturbing element.

In order to obviate the discrepancies which must arise in the use of various kinds of pendulums for simultaneous observations in different places, Bertelli and Rossi propose a normal 'tromometer,' of which a drawing is given. The length of the pendulum is $1\frac{1}{2}$ meters, the weight 100 grammes, and it makes forty-nine free oscillations in a minute. To the bottom of the pendulum is attached a horizontal disk, on the underside of which are engraved two fine lines at right-angles to one another. These lines are observed, after total internal reflection in a glass prism placed immediately below the disk, by a horizontal microscope, furnished with a micrometer. The azimuth of the deflection of the vertical is observed by a position-circle.

This paper also contains a description of the author's observatory at Rocca di Papa. It is established in a cave at 700 meters above the sea, on the external slope of the extinct Latian volcano. There is a large central pendulum hanging from the roof, and there are four others with different weights and lengths hanging in tubes cut in the native rock. Only the ends of these pendulums are visible, and they are protected by glass at the visible parts. A great part of this paper is occupied with descriptions of seismometers, and this is outside the scope of the present Report.

In presenting a pamphlet by Father Bertelli, entitled 'Riassunto delle osservazioni microsismiche, &c.,' to the Academy ('Comptes Rendus,' 1877, vol. 84, p. 465), M. d'Abbadie summarises Bertelli's conclusions somewhat as follows:—

The oscillation of the pendulum is generally parallel to valleys or chains of mountains in the neighbourhood. The oscillations are independent of local tremors, velocity and direction of wind, rain, change of temperature, and atmospheric electricity.

Pendulums of different lengths betray the movements of the soil in different manners, according to the agreement or disagreement of their free-periods with the period of the terrestrial vibrations.

The disturbances are not strictly simultaneous in the different towns of Italy, but succeed one another at short intervals.

After earthquakes the 'tromometric' or microseismic movements are especially apt to be in a vertical direction. They are always so when the earthquake is local, but the vertical movements are sometimes absent when the shock occurs elsewhere. Sometimes there is no movement at all, even when the shock occurs quite close at hand.

The positions of the sun and moon appear to have some influence on the movements of the pendulum, but the disturbances are especially frequent when the barometer is low.

The curves of 'the monthly means of the tromometric movement' exhibit the same forms in the various towns of Italy, even those which are distant from one another.

The maximum of disturbance occurs near the winter solstice and the minimum near the summer solstice; this agrees with Mallet's results about earthquakes.

At Florence a period of earthquakes is presaged by the magnitude and frequency of pendulous movements in a vertical direction. These movements are observable at intervals and during several hours after each shock.

At page 103 of the first part of the 'Bulletino' for 1878 (?), there is a review of a work by Giulio Grablovitz, 'Dell' attrazione luni-solare in relazione coi fenomeni mareo-sismici,' Milano, Tipografia degli Ingegneri, 1877.

In this work it appears that M. Grablovitz attributes a considerable part of the deviations of the vertical to bodily tides in the earth, but as he apparently enters into no computations to show the competency of this cause to produce the observed effects, it does not seem necessary to make any further comment on his views.

At page 99 of the volume for September–December, 1878, Rossi writes on the use of the microphone for the purpose of observing earthquakes ('Il microfono nella meteorologia endogena'). He begins by giving an account of a correspondence, beginning in 1875, between himself and Count Giovanni Mocenigo,[1] of Vicenza, who seems to have been very near to the discovery of the microphone. When the invention of the microphone was announced, Mocenigo and Armellini adopted it for their experiments, and came to the conclusion that the mysterious noises which they heard arose from minute earthquakes or microisms.

Rossi then determined to undertake observations in his cavern at Rocca di Papa, with a microphone, made of silver instead of carbon, mounted on a stone beam. The sensitiveness of the instrument could be regulated, and he found that it was not much influenced by external noises.

The instrument was placed 20 meters underground, and remote from

[1] Count Mocenigo has recently published at Vicenza a book on his observations. It is reviewed in *Nature* for July 6, 1882.

houses and carriage-roads. It was protected against insects, and was wrapped up in wool. Carpet was spread on the floor of the cave to deaden the noise from particles of stone which might possibly fall. Having established his microphone, he waited till night and then heard noises which he says revealed 'natural telluric phenomena.' The sounds which he heard he describes as 'roarings, explosions occurring isolated or in volleys, and metallic or bell-like sounds' [fremiti, scopii isolati o di moschetteria, e suoni metallici o di campana]. They all occurred mixed indiscriminately, and rose to maxima at irregular intervals. By artificial means he was able to cause noises which he calls 'rumbling (?) or crackling' [rullo o crepito]. The roaring [fremito] was the only noise which he could reproduce artificially, and then only for a moment. It was done by rubbing together the conducting wires, in the same manner as the rocks must rub against one another when there is an earthquake.

A mine having been exploded in a quarry at some distance, the tremors in the earth were audible in the microphone for some seconds subsequently.

There was some degree of coincidence between the agitation of the pendulum-seismograph and the noises heard with the microphone.

At a time when Vesuvius became active, Rocca di Papa was agitated by microsisms, and the shocks were found to be accompanied by the very same microphonic noises as before. The noises sometimes became 'intolerably loud;' on one occasion in the middle of the night, half an hour before a sensible earthquake. The agitation of the microphone corresponded exactly with the activity of Vesuvius.

Rossi then transported his microphone to Palmieri's Vesuvian observatory, and worked in conjunction with him. He there found that each class of shock had its corresponding noise. The sussultorial shocks, in which I conceive the movement of the ground is vertically up and down, gave the volleys of musketry [i colpi di moschetteria], and the undulatory shocks gave the roarings [i fremiti]. The two classes of noises were sometimes mixed up together.

Rossi makes the following remarks: 'On Vesuvius I was put in the way of discovering that the simple fall and rise in the ticking which occurs with the microphone [battito del orologio unito al microfono] (a phenomenon observed by all, and remaining inexplicable to all) is a consequence of the vibration of the ground.' This passage alone might perhaps lead one to suppose that clockwork was included in the circuit; but that this was not the case, and that 'ticking' is merely a mode of representing a natural noise, is proved by the fact that he subsequently says that he considers the ticking to be 'a telluric phenomenon.'

Rossi then took the microphone to the Solfatara of Pozzuoli, and here, although no sensible tremors were felt, the noises were so loud as to be heard simultaneously by all the people in the room. The ticking was quite masked by other natural noises. The noises at the Solfatara were imitated by placing the microphone on a vessel of boiling water. Other seismic noises were then imitated by placing the microphone on a marble slab, and scratching and tapping the under surface of it.

The observations on Vesuvius led him to the conclusion that the earthquake oscillations have sometimes fixed nodes and loops, for there were places on the mountain where no effects were observed. Hence, as

he remarks, although there may sometimes be considerable agitation in an earthquake, the true centre of disturbance may be very distant.

In conclusion Rossi gives a description of a good method of making a microphone. A common nail has a short piece of copper wire wound round it, and the other end of the wire is wound round a fixed metallic support. The nail thus stands at the end of a weak horizontal spring; but the nail is arranged so that it stands inclined to the horizon, instead of being vertical. The point of the nail is then put to rest on the middle of the back of a silver watch, which lies flat on a slab. The two electrodes are the handle of the watch and the metallic support. He says that this is as good as any instrument. The telephone is a seismological instrument, and therefore, strictly speaking, beyond the scope of this Report; but as some details of its use have already been given, I will here quote portions of an interesting letter by Prof. John Milne, of the Imperial Engineering College of Tokio, which appeared in 'Nature' for June 8, 1882. Mr. Milne writes:—

'In order to determine the presence of these earth-tremors, at the end of 1879 I commenced a series of experiments with a variety of apparatus, amongst which were microphones and sets of pendulum apparatus, very similar in general arrangement, but, unfortunately, not in refinement of construction, to the arrangements now being used in the Cavendish Laboratory.

'The microphones were screwed on to the heads of stakes driven in the ground, at the bottom of boxed-in pits. In order to be certain that the records which these microphones gave were not due to local actions, such as birds or insects, two distinct sets of apparatus were used, one being in the middle of the lawn in the front of my house, and the other in a pit at the back of the house. The sensitiveness of these may be learnt from the fact that if a small pebble was dropped on the grass within six feet of the pit, a distinct sound was heard in the telephone, and a swing produced in the needle of the galvanometer placed in connection with these microphones. A person running or walking in the neighbourhood of the pits, had each of his steps so definitely recorded, that a Japanese neighbour, Mr. Masato, who assisted me in the experiments, caused the swinging needle of his galvanometer to close an electric circuit and ring a bell, which, it is needless to say, would alarm a household. In the contrivance we have a hint as to how earth-tremors may be employed as thief-detectors.

'The pendulum apparatus, one of which consisted of a 20-lb. bob of lead at the end of 20 feet of pianoforte wire provided with small galvanometer mirrors and bifilar suspensions, were also used in pairs. With this apparatus a motion of the bob relatively to the earth was magnified 1,000 times, that is to say, if the spot of light which was reflected from the mirror moved a distance equal to the thickness of a sixpence, this indicated there had been a relative motion of the bob to the extent of 1,000th part that amount.

'The great evil which everyone has to contend with in Japan when working with delicate apparatus is the actual earthquakes, which stop or alter the rate of ordinary clocks.

'Another evil which had to be contended with was the wind, which shook the house in which my pendulums were supported, and I imagine the ground by the motion of some neighbouring trees. A shower of rain also was not without its effects upon the microphones. After many

months of tiresome observation, and eliminating all motions which by any possibility could have been produced by local influence, the general result obtained was that there were movements to be detected every day and sometimes many times per day. . . .

'A great assistance to the interpretation of the various records which an earthquake gives us on our seismographs is what I may call a barricade of post-cards. At the present moment Yedo is barricaded, all the towns around for a distance of 100 miles being provided with post-cards. Everyone of them is posted with a statement of the shocks which have been felt.

'For the months of October and November it was found from the records of the post-cards that nearly all the shocks came from the north and passed Yedo to the south-west. When coming in contact with a high range of mountains, they were suddenly stopped, as was inferred from the fact that the towns beyond this range did not perceive that an earthquake had occurred. This fact having been obtained, the barricade of post-cards has been extended to towns lying still farther north. The result of this has been that several earthquake origins have, so to speak, been surrounded or coralled, whilst others have been traced as far as the seashore. For the latter shocks, earthquake-hunting with post-cards has had to cease, and we have solely to rely upon our instruments. Having obtained our earthquake centres, at one or more of these our tremor instruments might be erected, and it would soon be known whether an observation of earth-tremors would tell us about the coming of an earthquake as the cracklings of a bending do about its approaching breakage. To render these experiments more complete, and to determine the existence of a terrain tide, a gravitimeter might be established. I mention this because if terrain tides exist, and they are sufficiently great from a geological point of view, it would seem that they might be more pronounced and therefore easier to measure in a country like Japan, resting in a heated and perhaps plastic bed, than in a country like England, where volcanic activity has so long ceased, and the rocks are, comparatively speaking, cold and rigid, if an instrument, sufficiently delicate to detect differences in the force of gravity, in consequence of our being lifted farther from the centre of the earth every time by the terrain tide as it passed between (*sic*) our feet, could be established in conjunction with the experiments on earth-tremors.'

The only account which I have been able to find of M. Bouquet de la Grye's observations (mentioned in the last Report) is contained in the 'Comptes Rendus' for March 22, 1875, page 725. M. Bouquet writes:—

'. . . The observation of the levels of our meridian telescopes put us on the track of a curious fact. Not only is Campbell Island subject to earthquakes, but it also exhibits movements when the great swell falls in breakers on the coast. I thought that it would be interesting to study this new phenomenon. The instrument, which was quickly put together, consisted of a steel wire supporting a weight, to which was soldered a needle; the movements of the weight were amplified 240 times by means of a lever; by passing an electric current through this multiplying pendulum, which was terminated at the bottom by a small cup of amalgamated tin, regular oscillations of $\frac{1}{1000}$th of a mm. could be registered. I propose to repeat these observations with a pendulum of

much larger amplifying power, so as to try to register the variations of the plumb-line.'

In a letter to me, M d'Abbadie mentions an attempt by Brunner to improve M. Bouquet de la Grye's apparatus, but considers that the attempt was a failure.

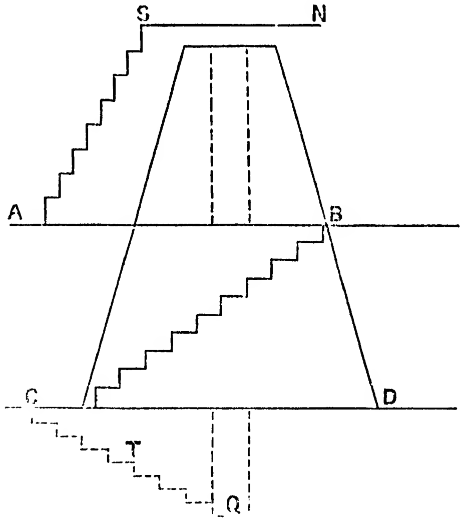
He also tells me that Delaunay directed M. Wolf to devise an apparatus for detecting small deviations of the vertical, and that the latter, without M. d'Abbadie's knowledge, adopted his rejected idea of a pendulum, about 30 meters long, bearing a prism at the end by reflection from which a scale was to be read by means of a distant small refractor. The pendulum was actually set up, but the wire went on twisting and untwisting until Delaunay's death, and no observations were made with it. Our own experience is enough to show that nothing could have been made of such an instrument.

M. d'Abbadie gives further explanations of a passage in his own paper about the arrangements for the staircases for access to and observation with his Nadirane. In writing the Report of 1881 I had found the description of the arrangements difficult to understand.

The woodcut below is a copy of the rough diagram that he sent me.

There were three staircases:—

T cut in the rock; C B to ascend from the cellar-flags C D; and, lastly, A S to mount from the boarded ground floor, A B, to the small floor S N, which was hung from the roof. The two upper staircases did not touch the truncated cone of concrete anywhere.



Judging from this figure, I imagine that the concrete cone has an ·rnal slope of ten in one, instead of one in ten as stated in last year's ·t; the French expression was 'une inclinaison d'un dixième.'

''Abbadie informs me that the apparently curious phenomenon of ·es fuyantes,' which were observed in the reflection from the ·cury, to which we drew attention last year, was of no signifi- ·ose from the currents of air caused by a candle left standing e T cut in the rock. The light was required for pouring

out the mercury, and it was left burning whilst the observation was being taken; but now that this operation is done entirely from above, the phenomenon has disappeared.

In a paper entitled 'Recherches sur la Verticale' (Ann. de la Soc. Scient. de Bruxelles, 1881), M. d'Abbadie continues the account of his observations with his instrument, called by him a Nadirane. It was described in the last year's Report, and some further details have been given above. A portion of this paper refers to his old observations, and gives further important details as to the exact method of making observations, and of various modifications which have been introduced.

Each complete observation consists of the following processes:—measurement of the distance between the cross-wires and their image, (1) in the meridian, (2) in the prime vertical, (3) in the N.W. azimuth, (4) observation of barometer, (5) of thermometer, (6) of direction and force of the wind, (7) condition and movement of the image estimated with the micrometer, (8) condition of the heavens, (9) of the breakers called 'les Criquets,' which can be observed from the neighbouring room.

This last is to determine whether it is possible to have a rough sea with a calm image; a condition which has not hitherto been observed. This statement seems somewhat contradictory of the following:—

'Aucunes des variations dans les circonstances concomitantes n'a paru se rattacher à l'état de l'image qui, pendant des journées entières, paraît tantôt belle, tantôt faible, et parfois même disparaît entièrement, bien que ce dernier inconvénient ait été évité en grande partie par l'usage d'un récipient en bois à fond rainé pour contenir le mercure.' I presume we are to understand that the roughness of the sea and the badness of the image is the only congruence hitherto observed.

M. d'Abbadie's observations on the effect of the tides will be referred to in the Appendix to this Report. He then discusses the various causes which may perhaps influence the vertical.

The variations of air-temperature are insufficient, because the vertical has been seen to vary $2''{\cdot}4$ in six hours. If the effects are to be attributed to variations in the temperature of the rock, it would be necessary to suppose that that temperature varies discontinuously, which it is difficult to admit.

If it be supposed that the changes take place in the instrument itself, the like must be true of astronomical instruments. And there is no reason to admit the reality of such strange variations.

Another cause, more convenient because more vague, is variation of a chemical or mechanical nature in the crust of the earth. But if this be so, why does the vertical ever return to its primitive position? Another cause may be variation in the position of the earth's axis of rotation.

The azimuthal variations in astronomical instruments, referred to by M. d'Abbadie (see a paper by Mr. Henry, vol. 8, p. 134, 'Month. Not. R.A.S.'), are difficult to explain without having recourse to such variation in the axis of rotation.

He also tells us that Ellis (vol. 29, 1861, p. 45, 'Mem. R.A.S.') has discussed the Greenwich observations from 1851 to 1858. A comparison of the results obtained from two neighbouring meridian instruments seemed to show that the azimuthal variations are partly purely instrumental.

M. d'Abbadie's paper contains diagrams illustrating the variations of the vertical observed with the Nadirane during nearly two years. He sums up the results as follows:—

'En résumé le maximum d'écart du sud au nord entre le fil et son image a été egal à 49``·2 (this is 15″·94; it seems as though this should be twice the deviation of the vertical) le 30 Novembre à 8h. 43m. du matin. Ce même jour, à 7h. 28m., on a lu 40``·1, chiffre porté ici au tableau, et 37``·6 seulement à 1h. 32m. du soir. Dans l'espace de six heures la verticale a donc varié de 2``·5 ou 0″·81 (as this is the deviation of the image, should not the deviation of the vertical be half as much ?). Le minimum de l'année, ou 3·06, fut atteint le 19 Janvier à 3h. 3m. du matin, ainsi que le 21 du même mois à midi, bien qu'on eût observé 3·44 et 3·30 dans les matinées de ces deux jours, ainsi qu'on le voit au tableau ci-après . . . . Pendant l'année entière la verticale, considérée selon le plan du méridien, a donc varié d'un angle de 12``·45 ou 4″·034 . . . . On aura . . . . 8``·3 ou 2″·7 pour la plus grande variation dans le sens Est-Ouest où l'on nivelle les tourillons des lunettes méridiennes.'

Towards the end M. d'Abbadie makes the excellent remark, that in discussing latitudes and declinations of stars, account should be taken of the instantaneous position of the vertical at the moment of taking the observation.

In the 'Archives des Sciences,' 1881, vol. 5, p. 97, M. P. Plantamour continues the account of his observations on oscillations of the soil at Sécheron, near Geneva. The account of the earlier observations, which we quoted from the 'Comptes Rendus' in our previous Report, are also contained in vol. 2 of the 'Archives,' p. 641. The paper to which we are now referring contains a graphical reproduction of the previous series of observations, as far as concerns the daily means.

The new series extends from October 1, 1879, to December 31, 1880, the disposition of the levels being the same as was described in our last Report. The observations were taken at 9 A.M. and 6 P.M., which hours are respectively a little before the diurnal minimum and maximum. The meaning of the terms maximum and minimum were somewhat obscure in the 'Comptes Rendus,' but I now find that the right interpretation was placed on M. Plantamour's words, for maximum means for the two levels E. end highest and S. end highest.

The N.S. level seems to have behaved very similarly in the two years of observation ; the total annual amplitudes in the two years being 4″·89 and 4″·56 respectively. In both years this level followed, with some retardation, the curve of external temperature, except between April and October, when the curves appear to be inverted. The E.W. level behaved very differently in the two years. In 1879 the E. end began to fall rapidly at the end of November, and continued to fall until December 26, when the reading was − 88″·71; it rose a little early in January and then fell again, so that on January 28, 1880, the reading was − 89″·95. The amplitude of the total fall (viz. from October 4, 1879, to January 28, 1880) was 95″·80. In the preceding year the amplitude was only 28″·08. The E. end has never recovered its primitive position, and remains nearly 80″ below its point of departure.

It is difficult to believe that so enormous a variation of level is normal, and one is tempted to suspect that there is some systematic error in his mode of observation. If such oscillations as these were to take place in an astronomical observatory, accurate astronomical observations would be almost impossible.

I have seen nothing which shows that M. Plantamour takes any special precaution with regard to the weight of the observer's body, nor

is it expressly stated that the observer always stands in exactly the same position, although, of course, it is probable that this is the case. It would be interesting, also, to learn whether any precautions have been taken for equalising the temperature of the level itself. To hold the hand in the neighbourhood of a delicate level is sufficient to quite alter the reading. In one of his letters to me M. d'Abbadie also remarks on the slow molecular changes in glass, which render levels untrustworthy for comparisons at considerable intervals of time. Although we must admire M. Plantamour's indomitable perseverance, it is to be regretted that his mode of observation is by means of levels; and we are compelled to regard, at least provisionally, these enormous changes of level either as a local phenomenon, or as due to systematic error in his mode of observation.

In the Report for 1881 we referred to some observations by Admiral Mouchez, made in 1856, on changes of level. A short paper by Admiral Mouchez on these observations will be found in the 'Comptes Rendus' for 1878, vol. 87, p. 665. I now find that the observations were, in fact, discussed by M. Gaillot, in a paper entitled 'Sur la direction de la verticale à l'observatoire de Paris,' at p. 684 of the same volume. The paper consists of the examination of 1,077 determinations of latitude, made between 1856 and 1861, with the Gambey circle.

M. Gaillot concludes that the variation from year to year is accidental, and that the variation of latitude in the course of the year is represented by

$$\delta\lambda = +\ 0''\cdot20 \sin\left[\frac{360^\circ\ (t-95)}{365\cdot25}\right],$$

where t is the number of days since January 1.

By a comparison of day and night observations he concludes that there is no trace of a diurnal variation. On this we may remark that, if the maximum and minimum occur at 6 P.M. and 6 A.M. (which is, roughly speaking, what we found to be the case), then the diurnal oscillation must necessarily disappear by this method of treatment.

Individual observations ranged from $2''\cdot48$ above to $3''\cdot17$ below the mean. On this he remarks :—

'Ceux qui savent combien l'observation du nadir présente parfois de difficulté dans un observatoire situé au milieu d'une grande ville, ... ceux-là ne trouveront pas ces écarts exagérés, et ne croiront nullement avoir besoin de faire intervenir une déviation de la verticale pour les expliquer.'

M. Gaillot concludes by remarks adverse to any sensible deviations of the vertical.

It seems to me, however, that in the passage about the influence of the traffic of a great town, M. Gaillot begs the whole question by setting down to that disturbing influence all remarkable deviations of the vertical. Our observations, and those of many others, are entirely adverse to such a conclusion.

M. d'Abbadie, in a letter to me, also expresses himself as to the inconclusiveness of M. Gaillot's discussion.

He also tells me that M. Tisserand, in his observations of latitude in Japan, found variations amounting to nearly $7''$; and when asked 'How he could be so much in error,' answered 'That he was sure of his observations and calculations, but could not explain the cause of such variations.'

The following further references may perhaps be useful :—Maxwell's paper on the 306-day inequality in the earth's rotation, which was men-

tioned in the Report of last year, is in the 'Trans. Roy. Soc.' of Edinburgh, 1857, vol. 21, pp. 559–70. See also Bessel's 'Abhandlungen,' vol. 2, p. 42, vol. 3, p. 304. In 'Nature' for January 12, 1882 (p. 250), there is an account of the work of the Swiss Seismological Commission. The original sources appear to be a text-book on Seismology by Professor Heim, of Bern, the 'Annuaire' of the Physical Society of Bern, and the 'Archives des Sciences' of Geneva. I learn from M. d'Abbadie that Colonel Orff has been making systematic observations twice a day with levels at the Observatory at Munich, and that Colonel Goulier has been doing the same at Paris, with levels filled with bisulphide of carbon.

Appendix.

On Variations in the Vertical due to Elasticity of the Earth's Surface.
By G. H. Darwin, F.R.S.

1. *On the Mechanical Effects of Barometric Pressure on the Earth's Surface.*

The remarks of Signore de Rossi, on the observed connection between barometric storms and the disturbance of the vertical, have led me to make the following investigation of the mechanical effects which are caused by variations of pressure acting on an elastic surface. The results seem to show that the direct measurement of the lunar disturbance of gravity must for ever remain impossible.

The practical question is to estimate the amount of distortion to which the upper strata of the earth's mass are subjected, when a wave of barometric depression or elevation passes over the surface. The solution of the following problem should give us such an estimate.

Let an elastic solid be infinite in one direction, and be bounded in the other direction by an infinite plane. Let the surface of the plane be everywhere acted on by normal pressures and tractions, which are expressible as a simple harmonic function of distances measured in some fixed direction along the plane. It is required to find the form assumed by the surface, and generally the condition of internal strain.

This is clearly equivalent to the problem of finding the distortion of the earth's surface produced by parallel undulations of barometric elevation and depression. It is but a slight objection to the correctness of a rough estimate of the kind required, that barometric disturbances do not actually occur in parallel bands, but rather in circles. And when we consider the magnitude of actual terrestrial storms, it is obvious that the curvature of the earth's surface may be safely neglected.

This problem is mathematically identical with that of finding the state of stress produced in the earth by the weight of a series of parallel mountains. The solution of this problem has recently been published in a paper by me in the 'Philosophical Transactions' (Part II. 1882, pp. 187–230), and the solution there found may be adapted to the present case in a few lines.

The problem only involves two dimensions. If the origin be taken in the mean horizontal surface, which equally divides the mountains and valleys, and if the axis of z be horizontal and perpendicular to the moun-

tain chains, and if the axis of x be drawn vertically downwards, then the equation to the mountains and valleys is supposed to be

$$x = -h \cos \frac{z}{b},$$

so that the wave-length from crest to crest of the mountain ranges is $2\pi b$.

The solution may easily be found from the analysis of section 7 of the paper referred to. It is as follows:—

Let α, γ be the displacements at the point x, z vertically downwards and horizontally (α has here the opposite sign to the α of (44)). Let w be the density of the rocks of which the mountains are composed; g gravity; v modulus of rigidity, then

$$\left.\begin{aligned} \alpha &= \frac{1}{2v} b \left[x \frac{dW}{dx} - W \right] \\ \gamma &= \frac{1}{2v} bx \frac{dW}{dz} \\ \text{where } W &= -gwh\, e^{-x/b} \cos \frac{z}{b} \end{aligned}\right\} \quad . \quad . \quad . \quad (1)$$

From these we have at once

$$\left.\begin{aligned} \alpha &= \frac{gwh}{2v} b \left(1 + \frac{x}{b}\right) e^{-x/b} \cos \frac{z}{b} \\ \gamma &= \frac{gwh}{2v} x e^{-x/b} \sin \frac{z}{b} \\ \frac{d\alpha}{dz} &= -\frac{gwh}{2v}\left(1 + \frac{x}{b}\right) e^{-x/b} \sin \frac{z}{b} \end{aligned}\right\} \quad . \quad . \quad (2)^{1}$$

The first of these gives the vertical displacement, the second the horizontal, and the third the inclination to the horizon of strata primitively plane.

At the surface

$$\left.\begin{aligned} \alpha &= \frac{gwh}{2v} b \cos \frac{z}{b}, \quad \gamma = 0 \\ \frac{d\alpha}{dz} &= -\frac{gwh}{2v} \sin \frac{z}{b} \end{aligned}\right\} \quad . \quad . \quad . \quad (3)$$

Hence the maximum vertical displacement of the surface is $\pm\, gwhb/2v$, and the maximum inclination of the surface to the horizon is

$$\pm \operatorname{cosec} 1'' \times gwh/2v \text{ seconds of arc.}$$

[1] It is easy to verify that these values of α and γ, together with the value $p = gwh\, e^{-x/b} \cos z/b$ for the hydrostatic pressure, satisfy all the conditions of the problem, by giving normal pressure $gwh \cos z/b$ at the free surface of the infinite plane, and satisfying the equations of internal equilibrium throughout the solid. I take this opportunity of remarking that the paper from which this investigation is taken contains an error, inasmuch as the hydrostatic pressure is erroneously determined in section 1. The term $-W$ should be added to the pressure as determined in (3). This adds W to the normal stresses P, Q, R throughout the paper, but leaves the difference of stresses (which was the thing to be determined) unaffected. If the reader should compare the stresses, as determined from the values of α, γ in the text above, and from the value of p given in this note, with (38) of the paper referred to, he is warned to remember the missing term W.

Before proceeding further I shall prove a very remarkable relation between the slope of the surface of an elastic horizontal plane and the deflection of the plumb-line caused by the direct attraction of the weight producing that slope. This relation was pointed out to me by Sir William Thomson, when I told him of the investigation on which I was engaged; but I am alone responsible for the proof as here given. He writes that he finds that it is not confined simply to the case where the solid is incompressible, but in this paper it will only be proved for that case.

Let there be positive and negative matter distributed over the horizontal plane according to the law $wh \cos(z/b)$; this forms, in fact, harmonic mountains and valleys on the infinite plane. We require to find the potential and attraction of such a distribution of matter.

Now the potential of an infinite straight line, of line-density ρ, at a point distant d from it, is well known to be $-2\mu\rho \log d$, where μ is the attraction between unit masses at unit distance apart. Hence the potential V of the supposed distribution of matter at the point x, z, is given by

$$V = -2\mu wh \int_{-\infty}^{+\infty} \cos\frac{\zeta}{b} \log\sqrt{\{x^2 + (\zeta - z)^2\}}\, d\zeta$$

$$= -\mu whb\left\{\left[\sin\frac{\zeta}{b}\log\{x^2 + (\zeta - z)^2\}\right]_{-\infty}^{+\infty} - 2\int_{-\infty}^{+\infty} \frac{(\zeta - z)\sin(\zeta/b)}{x^2 + (\zeta - z)^2}\, d\zeta\right\}$$

It is not hard to show that the first term vanishes when taken between the limits.

Now put $t = \dfrac{\zeta - z}{x}$, so that $\sin\dfrac{\zeta}{b} = \sin\dfrac{tx}{b}\cos\dfrac{z}{b} + \cos\dfrac{tx}{b}\sin\dfrac{z}{b}$, and we have

$$V = 2\mu whb \int_{-\infty}^{+\infty}\left(\sin\frac{tx}{b}\cos\frac{z}{b} + \cos\frac{tx}{b}\sin\frac{z}{b}\right)\frac{t\,dt}{1 + t^2}$$

But it is known[1] that

$$\int_{-\infty}^{+\infty} \frac{t \sin ct\, dt}{1 + t^2} = \pi e^{-c}, \quad \int_{-\infty}^{+\infty} \frac{t \cos ct}{1 + t^2}\, dt = 0.$$

Therefore $$V = 2\pi\mu whb e^{-x/b} \cos\frac{z}{b}.$$

If g be gravity, a earth's radius, and δ earth's mean density, $2\pi\mu = \dfrac{3g}{2a\delta}$.

And $$V = \frac{3gwh}{2a\delta} b e^{-x/b} \cos\frac{z}{b} \quad . \quad . \quad . \quad . \quad (4)$$

The deflection of the plumb-line at any point on the surface denoted by $x = 0$, and z, is clearly dV/gdz, when $x = 0$. Therefore,

$$\text{the deflection} = -\frac{1}{g} \times \frac{3gwh}{2a\delta} \sin\frac{z}{b} \quad . \quad . \quad . \quad . \quad (5)$$

But from (2) the slope (or $\dfrac{da}{dz}$, when z is zero), is $-\dfrac{gwh}{2v}\sin\dfrac{z}{b}$.

Therefore deflection bears to slope the same ratio as v/g to $\frac{1}{3}a\delta$. This

[1] See Todhunter's *Int. Calc.*; Chapter on 'Definite Integrals.'

ratio is independent of the wave-length $2\pi b$ of the undulating surface, of the position of the origin, and of the azimuth in the plane of the line normal to the ridges and valleys. Therefore the proposition is true of any combination whatever of harmonic undulations, and as any inequality may be built up of harmonic undulations, it is generally true of inequalities of any shape whatever.

Now $a = 6{\cdot}37 \times 10^8$ cm., $\delta = 5\frac{2}{3}$; and $\frac{1}{3}a\delta = 12{\cdot}03 \times 10^8$ grammes per square centimeter. The rigidity of glass in gravitation units ranges from $1{\cdot}5 \times 10^8$ to $2{\cdot}4 \times 10^8$. Therefore the slope of a very thick slab of the rigidity of glass, due to a weight placed on its surface, ranges from 8 to 5 times as much as the deflection of the plumb-line due to the attraction of that weight. Even with rigidity as great as steel (viz., about 8×10^8), the slope is $1\frac{1}{2}$ times as great as the deflection.

A practical conclusion from this is that in observations with an artificial horizon the disturbance due to the weight of the observer's body is very far greater than that due to the attraction of his mass. This is in perfect accordance with the observations made by my brother and me with our pendulum in 1881, when we concluded that the warping of the soil by our weight when standing in the observing room was a very serious disturbance, whilst we were unable to assert positively that the attraction of weights placed near the pendulum was perceptible. It also gives emphasis to the criticisms we have made on M. Plantamour's observations—namely, that he does not appear to take special precautions against the disturbance due to the weight of the observer's body.

We must now consider the probable numerical values of the quantities involved in the barometric problem, and the mode of transition from the problem of the mountains to that of barometric inequalities.

The modulus of rigidity in gravitation units (say grammes weight per square centimeter) is v/g. In the problem of the mountains, wh is the mass of a column of rock of one square centimeter in section and of length equal to the height of the crests of the mountains above the mean horizontal plane. In the barometric problem, wh must be taken as the mass of a column of mercury of a square centimeter in section and equal in height to a half of the maximum range of the barometer.

This maximum range is, I believe, nearly two inches, or, let us say, 5 cm.

The specific gravity of mercury is 13·6, and therefore $wh = 34$ grammes.

The rigidity of glass is from 150 to 240 million grammes per square centimeter; that of copper 540, and of steel 843 millions.

I will take $v/g = 3 \times 10^8$, so that the superficial layers of the earth are assumed to be more rigid than the most rigid glass. It will be easy to adjust the results afterwards to any other assumed rigidity.

With these data we have $\dfrac{gwh}{2v} = \dfrac{5{\cdot}67}{10^8}$; also $\dfrac{648{,}000}{\pi} \times \dfrac{5{\cdot}67}{10^8} = 0''{\cdot}0117$.

It seems not unreasonable to suppose that 1500 miles ($2{\cdot}4 \times 10^8$ cm.) is the distance from the place where the barometer is high (the centre of the anti-cyclone) to that where it is low (the centre of the cyclone). Accordingly the wave-length of the barometric undulation is $4{\cdot}8 \times 10^8$ cm., and $b = 4{\cdot}8 \times 10^8 \div 6{\cdot}28$ cm., or, say, $b = {\cdot}8 \times 10^8$ cm.

Thus, with these data, $\dfrac{gwh}{2v}b = 4{\cdot}5$ cm.

We thus see that the ground is 9 cm. higher under the barometric depression than under the elevation.

If the sea had time to attain its equilibrium slope, it would stand $5 \times 13{\cdot}6$, or 68 cm. lower under the high pressure than under the low. But as the land is itself dépressed 9 cm., the sea would apparently only be depressed 59 cm. under the high barometer.

It is probable that, in reality, the larger barometric inequalities do not linger quite long enough over particular areas to permit the sea to attain everywhere its due slope, and therefore the full difference of water-level can only be attained occasionally.

On the other hand, the elastic compression of the ground must take place without any sensible delay. Thus it seems probable that the elastic compression of the ground must exercise a very sensible effect in modifying the apparent depression or elevation of the sea under high and low barometer.

It does not appear absolutely chimerical that, at some future time when both tidal and barometric observations have attained to great accuracy, an estimate might thus be made of the average modulus of rigidity of the upper 500 miles of the earth's mass.

Even in the present condition of barometric and tidal information, it might be interesting to make a comparison between the computed height of tide and the observed height, in connection with the distribution of barometric pressure. It is probable that India would be the best field for such an attempt, because the knowledge of Indian tides is more complete than that for any other part of the world. On the other hand we shall see in the following section that tidal observations on coast-lines of continents are liable to disturbance, so that an oceanic island would be a more favourable site.

It has already been shown that the maximum apparent deflection of the plumb-line, consequent on the elastic compression of the earth, amounts to $0''{\cdot}0117$, and this is augmented to $0''{\cdot}0146$ when we include the true deflection due to the attraction of the air. It is worthy of remark that this result is independent of the wave-length of the barometric inequality, and thus we get rid of one of the conjectural data.

Thus if we consider the two cases of high pressure to right and low to left, and of low pressure to right and high to left, we see that there will be a difference in the position of the plumb-line relatively to the earth's surface of $0''{\cdot}0292$. Even if the rigidity of the upper strata of the earth were as great as that of steel, there would still be a change of $0''{\cdot}011$.

A deflection of magnitude such as $0''{\cdot}03$ or $0''{\cdot}01$ would have been easily observable with our instrument of last year, for we concluded that a change of $\frac{1}{200}$th of a second could be detected, when the change occurred rapidly.

It was stated in our previous Report that at Cambridge the calculated amplitude of oscillation of the plumb-line due directly to lunar disturbance of gravity amounts to $0''{\cdot}0216$. Now as this is less than the amplitude due jointly to elastic compression and attraction, with the assumed rigidity (300 millions) of the earth's strata, and only twice the result if the rigidity be as great as that of steel, it follows almost certainly that from this cause alone the measurement of the lunar disturbance of gravity must be impossible with any instrument on the earth's surface.

Moreover the removal of the instrument to the bottom of the deepest

known mine would scarcely sensibly affect the result, because the flexure of the strata at a depth so small, compared with the wave-length of barometric inequalities, is scarcely different from the flexure of the surface.

The diurnal and periodic oscillations of the vertical observed by us were many times as great as those which have just been computed, and therefore it must not be supposed that more than a fraction, say perhaps a tenth, of those oscillations was due to elastic compression of the earth.

The Italian observers could scarcely, with their instruments, detect deflections amounting to $\frac{1}{100}$th of a second, so that the observed connection between barometric oscillation and seismic disturbance must be of a different kind.

It is not surprising that in a volcanic region the equalisation of pressure, between imprisoned fluids and the external atmosphere, should lead to earthquakes.

If there is any place on the earth's surface free from seismic forces, it might be possible (if the effect of tides as computed in the following section could be eliminated) with some such instrument as ours, placed in a deep mine, to detect the existence of barometric disturbance many hundreds of miles away. It would of course for this purpose be necessary to note the positions of the sun and moon at the times of observation, and to allow for their attraction.

2. *On the Disturbance of the Vertical near the Coasts of Continents due to the Rise and Fall of the Tide.*

Consider the following problem:—

On an infinite horizontal plane, which bounds in one direction an infinite incompressible elastic solid, let there be drawn a series of parallel straight lines, distant l apart. Let one of these be axis of y, let the axis of z be drawn in the plane perpendicular to the parallel lines, and let the axis of x be drawn vertically downwards through the solid.

At every point of the surface of the solid, from $z = 0$ to l, let a normal pressure $gwh\ (1 - 2z/l)$ be applied; and from $z = 0$ to $-l$ let the surface be free from forces. Let the same distribution of force be repeated over all the pairs of strips into which the surface is divided by the system of parallel straight lines. It is required to determine the strains caused by these forces.

Taking the average over the whole surface there is neither pressure nor traction, since the total traction on the half-strips subject to traction is equal to the total pressure on the half-strips subject to pressure.

The following is the analogy of this system with that which we wish to discuss: the strips subject to no pressure are the continents, the alternate ones are the oceans, g is gravity, w the density of water, and h the height of tide above mean water on the coast-line.

We require to find the slope of the surface at every point, and the vertical displacement.

It is now necessary to bring this problem within the range of the results used in the last section. In the first place, it is convenient to consider the pressures and tractions as caused by mountains and valleys whose outline is given by $x = -h\ (1 - 2z/l)$ from $z = 0$ to l, and $x = 0$ from $z = 0$ to $-l$. To utilise the analysis of the last section, it is necessary that the mountains and valleys should present a simple-harmonic

outline. Hence the discontinuous function must be expanded by Fourier's method. Known results of that method render it unnecessary to have recourse to the theorem itself. It is known that—

$$\pm \tfrac{1}{2}\pi - \tfrac{1}{2}\theta = \sin\theta + \tfrac{1}{2}\sin 2\theta + \tfrac{1}{3}\sin 3\theta + \ldots\ldots$$

$$-\tfrac{1}{2}\theta = -\sin\theta + \tfrac{1}{2}\sin 2\theta - \tfrac{1}{3}\sin 3\theta + \ldots\ldots$$

$$\tfrac{1}{2}\pi \mp \theta = \frac{4}{\pi}\left\{\cos\theta + \frac{1}{3^2}\cos 3\theta + \frac{1}{5^2}\cos 5\theta + \ldots\right\}$$

The upper sign being taken for values of θ between the infinitely small positive and $+\pi$, and the lower for values between the infinitely small negative and $-\pi$.

Adding these three series together we have—

$$2\left\{\tfrac{1}{2}\sin 2\theta + \tfrac{1}{4}\sin 4\theta + \ldots\right\} + \frac{4}{\pi}\left\{\cos\theta + \frac{1}{3^2}\cos 3\theta + \frac{1}{5^2}\cos 5\theta + \ldots\right\}$$

equal to $\pi - 2\theta$ from $\theta = 0$ to $+\pi$, and equal to zero from $\theta = 0$ to $-\pi$. Hence the required expansion of the discontinuous function is—

$$-\frac{2h}{\pi}\left\{\tfrac{1}{2}\sin 2\theta + \tfrac{1}{4}\sin 4\theta + \ldots\right\}$$

$$-\frac{4h}{\pi^2}\left\{\cos\theta + \frac{1}{3^2}\cos 3\theta + \frac{1}{5^2}\cos 5\theta + \ldots\right\} \quad \ldots\ldots (6)$$

where $$\theta = \frac{\pi z}{l} \quad \ldots\ldots\ldots\ldots\ldots\ldots (7)$$

For it vanishes from $z = -l$ to 0, and is equal to $-h(1 - 2z/l)$ from $z = 0$ to $+l$.

Now looking back to the analysis of the preceding section we see that if the equation to the mountains and valleys had been $x = -h\sin(z/b)$, a would have had the same form as in (2) but of course with sine for cosine, and γ would have changed its sign and a cosine would have stood for the sine. Applying then the solution (2) to each term of our expansion separately, and only writing down the solution for the surface at which $x = 0$, we have at once that $\gamma = 0$, and

$$a = \frac{gwh}{\pi v}\frac{l}{\pi}\left\{\frac{1}{2^2}\sin 2\theta + \frac{1}{4^2}\sin 4\theta + \frac{1}{6^2}\sin 6\theta + \ldots\right\}$$

$$+\frac{gwh}{\pi v}\cdot\frac{2l}{\pi^2}\left\{\cos\theta + \frac{1}{3^3}\cos 3\theta + \frac{1}{5^3}\cos 5\theta + \ldots\right\} \quad \ldots\ldots (8)$$

The slope of the surface is $\frac{da}{dz}$ or $\frac{\pi}{l}\frac{da}{d\theta}$; thus

$$\frac{da}{dz} = \frac{gwh}{\pi v}\left\{\tfrac{1}{2}\cos 2\theta + \tfrac{1}{4}\cos 4\theta + \tfrac{1}{6}\cos 6\theta + \ldots\right\}$$

$$-\frac{gwh}{\pi v}\cdot\frac{2}{\pi}\left\{\sin\theta + \frac{1}{3^2}\sin 3\theta + \frac{1}{5^2}\sin 5\theta + \ldots\right\} \quad \ldots\ldots (9)$$

The formulæ (8) and (9) are the required expressions for the vertical depression of the surface and for the slope.

It is interesting to determine the form of surface denoted by these equations. Let us suppose then that the units are so chosen that $gwhl/\pi^2 v$ may be equal to one. Then (8) becomes

$$a = \frac{1}{2^2}\sin 2\theta + \frac{1}{4^2}\sin 4\theta + \ldots + \frac{2}{\pi}\left\{\frac{1}{1^3}\cos\theta + \frac{1}{3^3}\cos 3\theta + \ldots\right\} \quad (10)$$

$$\frac{da}{d\theta} = \tfrac{1}{2}\cos 2\theta + \tfrac{1}{4}\cos 4\theta + \ldots - \frac{2}{\pi}\left\{\frac{1}{1^2}\sin\theta + \frac{1}{3^2}\sin 3\theta + \ldots\right\} \quad (11)$$

When θ is zero or $\pm\pi$, $da/d\theta$ becomes infinite, which denotes that the tangent to the warped horizontal surface is vertical at these points. The verticality of these tangents will have no place in reality, because actual shores shelve, and there is not a vertical wall of water when the tide rises, as is supposed to be the case in the ideal problem. We shall, however, see that in practical numerical application, the strip of sea-shore along which the solution shows a slope of more than 1″ is only a small fraction of a millimeter. Thus this departure from reality is of no importance whatever.

When $\theta = 0$ or $\pm\pi$,

$$a = \frac{2}{\pi}\left\{\frac{1}{1^3} + \frac{1}{3^3} + \frac{1}{5^3} + \ldots\right\} = \frac{2}{\pi} \times 1{\cdot}052 = {\cdot}670;$$

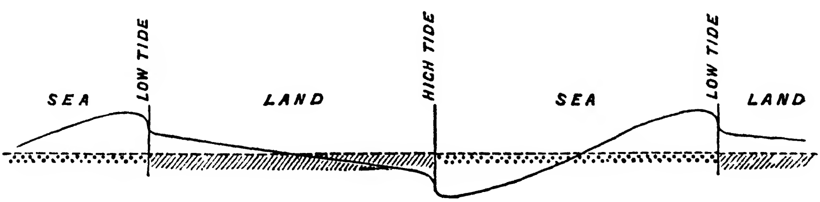
being $+$ when $\theta = 0$, and $-$ when $\theta = \pm\pi$.

When $\theta = \pm\frac{1}{2}\pi$, a vanishes, and therefore midway in the ocean and on the land there are nodal lines, which always remain in the undisturbed surface, when the tide rises and falls. At these nodal lines, defined by $\theta = \pm\frac{1}{2}\pi$,

$$\frac{da}{d\theta} = -\tfrac{1}{2}\log_e 2 \mp \frac{2}{\pi}\left\{\frac{1}{1^3} - \frac{1}{3^3} + \frac{1}{5^3} - \ldots\right\}$$

$$= -{\cdot}3466 \mp {\cdot}6168 = -{\cdot}9634 \text{ and } +{\cdot}2702$$

Thus the slope is greater at mid-ocean than at mid-land. By assuming θ successively as $\frac{1}{6}\pi$, $\frac{1}{4}\pi$, $\frac{1}{3}\pi$, and summing arithmetically the strange series which arise, we can, on paying attention to the manner in which the signs of the series occur, obtain the values of a corresponding to $0, \pm\frac{1}{6}\pi, \pm\frac{1}{4}\pi, \pm\frac{2}{6}\pi, \pm\frac{3}{6}\pi, \pm\frac{4}{6}\pi, \pm\frac{5}{6}\pi, \pm\frac{6}{6}\pi$. The resulting values, together with the slopes as obtained above, are amply sufficient for drawing a figure, as in the annexed diagram.



The straight line is a section of the undisturbed level, the shaded part being land, and the dotted sea. The curve shows the distortion, when warped by high and low tide as indicated.

The scale of the figure is a quarter of an inch to $\frac{1}{6}\pi$ for the abscissas,

and a quarter of an inch to unity for the ordinates; it is of course an enormous exaggeration of the flexure actually possibly due to tides.

It is interesting to note that the land regions remain very nearly flat, rotating about the nodal line, but with slight curvature near the coasts. It is this curvature, scarcely perceptible in the figure, which is of most interest for practical application.

The series (8) and (9) are not convenient for practical calculation in the neighbourhood of the coast, and they must be reduced to other forms. It is easy, by writing the cosines in their exponential form, to show that

$$\cos\theta + \tfrac{1}{2}\cos 2\theta + \tfrac{1}{3}\cos 3\theta + \ldots = -\log_e(\pm 2\sin\tfrac{1}{2}\theta) \quad \ldots (13)$$
$$\cos\theta - \tfrac{1}{2}\cos 2\theta + \tfrac{1}{3}\cos 3\theta + \ldots = \log_e(2\cos\tfrac{1}{2}\theta) \quad \ldots (14)$$

Where the upper sign in (13) is to be taken for positive values of θ and the lower for negative.

For the small values of θ, for which alone we are at present concerned, the series (13) becomes $-\log_e(\pm\theta)$ and the lower $\log_e 2$.

Taking half the difference and half the sum of the two series we have

$$\tfrac{1}{2}\cos 2\theta + \tfrac{1}{4}\cos 4\theta + \ldots\ldots = -\tfrac{1}{2}\log(\pm\theta) - \tfrac{1}{2}\log 2 \quad \ldots (15)$$
$$\cos\theta + \tfrac{1}{3}\cos 3\theta + \tfrac{1}{5}\cos 5\theta + \ = -\tfrac{1}{2}\log(\pm\theta) + \tfrac{1}{2}\log 2 \quad \ldots (16)$$

Integrating (16) with regard to θ, and observing that the constant introduced on integration is zero, we have

$$\sin\theta + \frac{1}{3^2}\sin 3\theta + \frac{1}{5^2}\sin 5\theta = -\tfrac{1}{2}\theta\,[\log(\pm\theta) - 1] + \tfrac{1}{2}\theta\log 2 \ . (17)$$

Then from (15) and (17)

$$\tfrac{1}{2}\cos 2\theta + \tfrac{1}{4}\cos 4\theta + \ldots - \frac{2}{\pi}\left\{\sin\theta + \frac{1}{3^2}\sin 3\theta + \ldots\right\}$$
$$= -\tfrac{1}{2}\left(1 - \frac{2\theta}{\pi}\right)\log(\pm\theta) - \tfrac{1}{2}\left(1 + \frac{2\theta}{\pi}\right)\log 2 - \frac{\theta}{\pi} \quad \ldots (18)$$

Integrating (15), and observing that the constant is zero we have,

$$\frac{1}{2^2}\sin 2\theta + \frac{1}{4^2}\sin 4\theta + \ldots = -\tfrac{1}{2}\theta\,[\log(\pm\theta) - 1] - \tfrac{1}{2}\theta\log 2 \ (19)$$

Integrating (17) and putting in the proper constant to make the left side vanish when $\theta = 0$, we have

$$\frac{1}{1^3} + \frac{1}{3^3} + \frac{1}{5^3} + \ldots - \left(\frac{1}{1^3}\cos\theta + \frac{1}{3^3}\cos 3\theta + \ldots\right)$$
$$= -\tfrac{1}{4}\theta^2\log(\pm\theta) + \tfrac{1}{4}\theta^2(\tfrac{3}{2} + \log 2) \quad \ldots (20)$$

For purposes of practical calculation θ may be taken as so small that the right-hand side of (18) reduces to $-\tfrac{1}{2}\log(\pm 2\theta)$, and the right-hand sides of (19) and (20) to zero.

Hence by (8) and (9), we have in the neighbourhood of the coast

$$\left.\begin{aligned} a &= \frac{gwh}{\pi v} \times \frac{2l}{\pi^2}\left[\frac{1}{1^3} + \frac{1}{3^3} + \frac{1}{5^3} + \ldots\right] \\ &= \frac{gwh}{\pi v} \times \frac{l}{\pi^2} \times 2{\cdot}1037 \\ \frac{da}{dz} &= -\frac{gwh}{2\pi v}\log_e 10\,\log_{10}\frac{2\pi z}{l} \end{aligned}\right\} \quad \ldots (21)$$

I shall now proceed to compute from the formulæ (21) the depression of the surface and the slope, corresponding to such numerical data as seem most appropriate to the terrestrial oceans and continents.

Considering that the tides are undoubtedly augmented by kinetic action, we shall be within the mark in taking h as the semi-range of equilibrium tide. At the equator the lunar tide has a range of about 53 cm., and the solar tide is very nearly half as much. Therefore at spring-tides we may take $h = 40$ cm. It must be noticed that the highness of the tides, say 15 or 20 feet, near the coast is due to the shallowing of the water, and it would not be just to take such values as representing the tides over large areas; w, the density of the water is, of course, unity.

If we suppose it is the Atlantic Ocean and the shores of Europe with Africa, and of North and South America, which are under consideration, it is not unreasonable to take l as 3,900 miles or $6 \cdot 28 \times 10^8$ cm. Then $2\pi z/l = z \times 10^{-8}$.

Taking v/g as 3×10^8, that is to say, assuming a rigidity greater than that of glass, we have for the slope in seconds of arc, at a distance z from the sea-shore

$$\left.\begin{array}{l} \operatorname{cosec} 1'' \times \dfrac{40}{2\pi \times 3 \times 10^8} \times \log_e 10 \times (8 - \log_{10} z) \\ = 0''\cdot 01008\ (8 - \log_{10} z) \end{array}\right\} \quad . \; . \; (22)$$

From this the following table may be computed by simple multiplication :—

Distance from mean water-mark		Slope
1 cm.	= 1 cm.	0″·0806
10 cm.	= 10 cm.	·0706
10^2 cm.	= 1 meter	·0605
10^3 cm.	= 10 m.	·0504
10^4 cm.	= 100 m.	·0403
10^5 cm.	= 1 kilom.	0″·0302
10^6 cm.	= 10 kilom.	·0202
2×10^6 cm.	= 20 kilom.	·0170
5×10^6 cm.	= 50 kilom.	·0131
10^7 cm.	= 100 kilom.	·0101

On considering the formula (22) it appears that z must be a very small fraction of a millimeter before the slope becomes even as great as 1′. This proves that the rounded nick in the surface, which arises from the discontinuity of pressure at our ideal mean water-mark, is excessively small, and the vertical displacement of the surface is sensibly the same, when measured in centimeters, on each side of the nick, in accordance with the first of (21).

The result (5) of section 1 shows that, with rigidity 3×10^8, the true deflection of plumb-line due to attraction of the water is a quarter of the slope. Hence an observer in a gravitational observatory at distance z from mean water-mark, would note deflections from the mean position of the vertical $1\frac{1}{4}$ times as great as those computed above. And as high

water changes to low, there would be oscillations of the vertical $2\frac{1}{2}$ times as great. We thus get the practical results in the following table :—

Distance of observatory from mean water-mark	Amplitude of apparent oscillation of the vertical
10 meters	$0''\cdot126$
100 m.	$\cdot101$
1 kilom.	$\cdot076$
10 kilom.	$\cdot050$
20 kilom.	$\cdot042$
50 kilom.	$\cdot035$
100 kilom.	$\cdot025$

It follows, from the calculations made for tracing the curve, that halfway across the continent (that is to say, 3,142 kilometers from either coast) the slope is $\frac{648,000}{\pi} \times \frac{gwh}{\pi v} \times \cdot2703$ seconds of arc, $= 0''\cdot00237$; and the range of apparent oscillation is $0''\cdot006$.

In these calculations the width of the sea is taken as 6,283 kilometers. If the sea be narrower, then to obtain the same deflections of the plumb-line, the observatory must be moved nearer the sea in the same proportion as the sea is narrowed. If, for example, the sea were 3,142 kilometers wide, then at 10 kilometers from the coast the apparent amplitude of deflection is $0''\cdot042$. If the range of tide is greater than that here assumed (viz., 80 cm.), the results must be augmented in the same proportion. And, lastly, if the rigidity of the rock be greater or less than the assumed value (viz., 3×10^8) the part of the apparent deflection depending on slope must be diminished or increased in the inverse proportion to the change in rigidity.

I think there can be little doubt that in narrow seas the tides are generally much greater than those here assumed; and it is probable that at a gravitational observatory actually on the sea-shore on the south-coast of England, apart from seismic changes, perceptible oscillations of the vertical would be noted.

Sir William Thomson has made an entirely independent estimate of the probable deflection of the plumb-line at a seaside gravitational observatory.[1] He estimates the attraction of a slab of water, 10 feet thick (the range of tide), 50 miles broad perpendicular to the coast, and 100 miles long parallel with coast, on a plummet 100 yards from the low-water mark, and opposite the middle of the 100 miles of length. He thinks this estimate would very roughly represent the state of things say at St. Alban's Head. He finds then that the deflection of the plumb-line as high tide changes to low would be $\frac{1}{4000000}$th of the unit angle, or $0''\cdot050$. The general theorem proved above, as to the proportionality of slope to attraction, shows that, with rigidity 3×10^8 for the rocks of which the earth is formed, the apparent deflection of the plumb-line would amount to $0''\cdot25$.

It is just possible that a way may in this manner be opened for determining the modulus of rigidity of the upper 100 or 200 miles of the earth's surface, although the process would be excessively laborious. The tides of the British Channel are pretty well known, and therefore it would be possible by very laborious quadratures to determine the deflection of the plumb-line due to the attraction of the tide at any time at a chosen station.

[1] Thomson and Tait's *Nat. Phil.* § 818.

If then the deflection of the plumb-line could be observed at that station (with corrections applied for the positions of the sun and moon), the ratio of the calculated to the observed and corrected deflection, together with the known value of the earth's radius and mean density, form the materials for computing the rigidity. But such a scheme would be probably rendered abortive by just such comparatively large and capricious oscillations of the vertical, as we, M. d'Abbadie and others, have observed.

It is interesting to draw attention to some observations of M. d'Abbadie on the deflections of the vertical due to tides. His observatory (of which an account was given in the Report for 1881) is near Hendaye in the Pyrenees, and stands 72 meters above, and 400 meters distant, from the sea. He writes :[1]—

'J'ai réuni 359 comparaisons d'observations spéciales faites lors du maximum du flot et du jusant; 243 seulement sont favorables à la théorie de l'attraction exercée par la masse des eaux, et l'ensemble des résultats pour une différence moyenne de marées égale à 2·9 mètres donne un résultat moyen de 0''·56 ou 0''·18 pour le double de l'attraction angulaire vers le Nord-Ouest. Ceci est conforme à la théorie, car les différences observées doivent être partagées par moitié, selon la loi de la réflexion; mais comme il y a toujours de l'inattendu dans les expériences nouvelles, on doit ajouter que sur les 116 comparaisons restantes il y en a eu 57 où le flot semble repousser le mercure au lieu de l'attirer. Mes résultats ont été confirmés pendant l'hiver dernier par M. l'abbé Artus, qui a eu la patience de comparer ainsi 71 flots et 73 jusants consécutifs, de janvier à mars 1880. Lui aussi a trouvé un tiers environ de cas défavorables à nos théories admises. On est donc en droit d'affirmer que si la mer haute attire le plus souvent le pied du fil à plomb, il y a une, et peut-être plusieurs, autres forces en jeu pour faire varier sa position.'

We must now consider the vertical displacement of the land near the coast. In (21) it is shown to be $a_0 = \frac{gwh}{\pi v} \times \frac{l}{\pi^2} \times 2{\cdot}1037$, where a_0 indicates the displacement corresponding to $z = 0$.

With the assumed values, $h = 40$, $v = 3 \times 10^8$, $l = 6{\cdot}28 \times 10^8$, I find $a_0 = 5{\cdot}684$ cm. Hence the amplitude of vertical displacement is 11·37 cm. As long as hl remains constant this vertical displacement remains the same; hence the high tides of 10 or 15 feet which are actually observed on the coasts of narrow seas must probably produce vertical oscillations of quite the same order as that computed.

If the land falls the tide of course rises higher on the coast line than it would do otherwise; hence the apparent height of tide would be $h + a_0$. But this shows there is more water resting on the earth than according to the estimated value h; hence the depression of the soil is greater in the proportion $1 + a_0/h$ to unity; this again causes more tide, which reacts and causes more depression, and so on. Thus on the whole the augmentation of tide due to elastic yielding is in the ratio of

$$1 + \frac{a_0}{h} + \left(\frac{a_0}{h}\right)^2 + \left(\frac{a_0}{h}\right)^3 + \ldots \text{ or } \frac{1}{1 - a_0/h} \text{ to unity.}$$

This investigation is conducted on the equilibrium theory, and it neglects the curvature of the sea-bed, assuming that there is a uniform

[1] 'Recherches sur la Verticale,' *Ann. de la Soc. Scient. de Bruxelles*, 1881.

slope from mid-ocean to the sea-coast. The figure shows that this is not rigorously the case, but it is quite near enough for a rough approximation. The phenomena of the short period tides are so essentially kinetic that the value of this augmentation must remain quite uncertain, but for the long-period tides (the fortnightly and monthly elliptic) the augmentation must correspond approximately with the ratio

$$1 : \left(1 - \frac{gwl}{\pi^3 v} \times 2{\cdot}1037.\right)$$

The augmentation in narrow seas will be small, but in the Atlantic Ocean the augmenting factor must agree pretty well with that which I now compute.[1]

With the previous numerical values we have a_0/h (which is independent of h) equal to $\cdot1421$, and $1 - a_0/h = \cdot8579 = \frac{6}{7}$ very nearly.

Thus the long-period tides may probably undergo an augmentation at the coasts of the Atlantic in some such ratio as 6 to 7.

The influence of this kind of elastic yielding is antagonistic to that reduction of apparent tide, which must result from an elastic yielding of the earth's mass as a whole.

The reader will probably find it difficult to estimate what degree of probability of correctness there is in the conjectural value of the rigidity, which has been used in making the numerical calculations in this paper. The rigidity has not been experimentally determined for many substances, but a great number of experiments have been made to find Young's modulus. Now, in the stretching of a bar or wire the compressibility plays a much less important part than the rigidity, and the formula for Young's modulus shows that for an incompressible elastic solid the modulus is equal to three times the rigidity.[2] Hence a third of Young's modulus will form a good standard of comparison with the assumed rigidity, namely, 3×10^8 grammes weight per square centimeter. The following are a few values of a third of Young's modulus and of rigidity, taken from the tables in Sir William Thomson's article on Elasticity[3] in the 'Encyclopædia Britannica.'

Material	A third of Young's mod. and rigidity in terms of 10^8 grammes weight per sq. cm.
Stone	About 1·2
Slate	About 3 to 4
Glass	Rigidity 1·5 to 2·4
Ice	4·7
Copper	4 and rigidity 4·6 to 5·4
Steel	7 to 10 and rigidity 8·4

It will be observed that the assumed rigidity 3 is probably a pretty high estimate in comparison with that of the materials of which we know the superficial strata to be formed.

It is shown, in another paper read before the Association at this meeting, that the rigidity of the earth as a whole is probably as great as that of steel. That result is not at all inconsistent with the probability of the assumption that the upper strata have only a rigidity a little greater than that of glass.

[1] It has been pointed out to me since this meeting, by Sir William Thomson, that this kind of augmentation of apparent tide will only hold true with certain distributions of land.

[2] Thomson and Tait's *Nat. Phil.* § 683.

[3] Also published separately by Black, Edinburgh.

3. *On Gravitational Observatories.*

In the preceding sections estimates have been made of the amount of distortion which the upper strata of the earth probably undergo, from the shifting weights corresponding to barometric and tidal oscillations. These results appear to me to have an important bearing on the probable utility of gravitational observatories.

It is not probable, at least for many years to come, that the state of tidal and barometric pressure, for a radius of 500 miles round any spot on the earth's surface, will be known with sufficient accuracy to make even a rough approximation to the slope of the surface a possibility. And were these data known, the heterogeneity of geological strata would form a serious obstacle to the possibility of carrying out such a computation. It would do little in relieving us from these difficulties to place the observatory at the bottom of a mine.

Accordingly the prospect of determining experimentally the lunar disturbance of gravity appears exceedingly remote, and I am compelled reluctantly to conclude that continuous observations with gravitational instruments of very great delicacy are not likely to lead to results of any great interest. It appears likely that such an instrument, even in the most favourable site, would record incessant variations of which no satisfactory account could be given. Although I do not regard it as probable that such a delicate instrument should be adopted for regular continuous observations, yet, by choosing a site where the flexure of the earth's surface is likely to be great, it is conceivable that a rough estimate might be made of the average modulus of elasticity of the upper strata of the earth for one or two hundred miles from the surface.

These conclusions, which I express with much diffidence; are by no means adverse to the utility of a coarser gravitational instrument, capable, let us say, of recording variations of level amounting to 1″ or 2″. If barometric pressure, tidal pressure, and the direct action of the sun and moon, combined together to make apparent slope in one direction, then at an observatory remote from the sea-shore, that slope might perhaps amount to a quarter of a second of arc. Such a disturbance of level would not be important compared with the minimum deviations which could be recorded by the supposed instrument.

It would then be of much value to obtain continuous systematic observations, after the manner of the Italians, of the seismic and slower quasi-seismic variations of level.

I venture to predict that at some future time practical astronomers will no longer be content to eliminate variations of level merely by taking means of results, but will regard corrections derived from a special instrument as necessary to each astronomical observation.

Report of the Committee, consisting of Professor DEWAR, Dr. WILLIAMSON, Dr. MARSHALL WATTS, Captain ABNEY, Mr. STONEY, Professor HARTLEY, Professor McLEOD, Professor CAREY FOSTER, Professor A. K. HUNTINGTON, Professor EMERSON REYNOLDS, Professor REINOLD, Professor LIVEING, Lord RAYLEIGH, Dr. SCHUSTER, *and* Professor W. CHANDLER ROBERTS (*Secretary*), *appointed for the purpose of reporting upon the present state of our Knowledge of Spectrum Analysis.*

THE GENESIS OF SPECTRA. *By* Dr. SCHUSTER.

IT is the ambitious object of Spectroscopy to study the vibrations of atoms and molecules in order to obtain what information we can on the nature of the forces which bind them together. The vibrations we know must be of a very complicated nature, yet it is natural that not many years after Spectrum Analysis was raised to the rank of a science by the labours of Kirchhoff and Bunsen attempts were made to discover a law in the apparent irregularity with which different lines of the same element are distributed over the spectrum. If an atom can vibrate in more ways than one, it is certain that some connection must exist between the different periods, and this connection we may attempt to find out by trial. Or we may speculate on the causes which produce such vast differences in the chemical properties of some of the elements, while other elements have properties which resemble each other to an equally marked degree. We may be led on by such speculations to try whether we can trace any similarity in the periods of vibration of molecules which have similar chemical properties, or we may endeavour to classify the elements according to their spectra, and see whether such a classification would divide the elements into groups agreeing with those into which they have been divided by means of their chemical and physical behaviour.

When different elements combine together the vibrations of the compound molecule are not obtained by the simple addition of the periods of the elements. The spectrum of a molecule is entirely distinct from that of its elements, and we may well ask the question whether we can trace in the spectrum of the compound the influence of the different atoms composing it. Thus, for instance, we might trace some relationship between the spectra of the oxides, bromides, chlorides, or iodides of a metal and that of the metal itself, or we may in the absorption spectrum of a salt trace one part to the influence of the base, the other to the influence of the acid. Such and similar questions have been raised and have been partially answered. But we must not too soon expect the discovery of any grand and very general law, for the constitution of what we call a molecule is no doubt a very complicated one, and the difficulty of the problem is so great that were it not for the primary importance of the result which we may finally hope to obtain, all but the most sanguine might well be discouraged to engage in an inquiry which, even after many years of work, may turn out to have been fruitless. We know a great deal more about the forces which produce the vibrations of sound than about those which produce the vibrations of light. To find out the different tunes sent out by a vibrating system is a problem which may or may not be solvable in certain special cases, but it would baffle the most

skilful mathematician to solve the inverse problem and to find out the shape of a bell by means of the sounds which it is capable of sending out. And this is the problem which ultimately spectroscopy hopes to solve in the case of light. In the meantime we must welcome with delight even the smallest step in the desired direction.

It is the object of the present report to bring together the various attempts which have been made to trace a connection either between the vibrations of the same body, between those of different compounds of the same body, or finally between the vibrations of similarly constituted bodies.

I. *Connection between the different periods of Vibration of one Molecule.*

In some acoustical systems the different periods of vibration are connected together by means of a very simple law, and it was a natural idea to trace the same law if possible in the luminous vibrations of molecules. If the law holds good the periods of vibrations or the lengths of the waves of light sent out by molecules ought to be in the ratio of small integer numbers. The first published attempt to trace such a connection is due to Lecoq de Boisbaudran, who investigated the spectrum of nitrogen[1] with special reference to this point. The spectrum in question, which is the one appearing at low temperatures, is made up of two sets of bands, one reaching from the red into the green, and one reaching from the green into the violet. Lecoq de Boisbaudran tried to show that each band of the second set had a wave-length which was in the ratio of three to four, with a corresponding band of the first set. The author had, however, only a one prism spectroscope at his disposal, and the wave-lengths as determined by him could not possibly possess that accuracy which is necessary for an investigation of this nature. The more accurate measurements of Thalèn do not bear out Lecoq's result. Thus, for instance, two bands, 5064 and 6752, according to Lecoq, are nearly in the required ratio; if the agreement was perfect the latter number ought to be 6748; but Thalèn, though giving to the green band a number agreeing fairly well with Lecoq's, puts the red band at 6786, differing very considerably from 6754, the required value, if Thalèn's measurement for the green band is used. The other coincidences pointed out by Lecoq are similarly disproved by more exact measurements. Inquiries such as those attempted by Lecoq can only be conducted with advantage when we have measured to the highest degree of accuracy which we can obtain in our best instruments, and many of the apparent harmonic ratios which at one time were thought to hold good had to give way when subjected to a severer test. Mr. Johnstone Stoney,[2] realising this fact, has, however, pointed out one set of harmonic ratios which seems to hold good to a high degree of accuracy. We know of four hydrogen lines in the visible part of the spectrum, and three of these are found to be in the ratios of 20 : 27 : 32. The wave-lengths of these lines are amongst those best determined by Ångström, and they were corrected by Mr. Stoney for atmospheric refraction. The following table exhibits the very remarkable coincidence.

TABLE I.

Observed Wave-length	Calculated Values	Differences
h = 4102·37	$\frac{1}{32} \times 131277{\cdot}14 = 4102{\cdot}41$	+ 0·04
F = 4862·11	$\frac{1}{27} \times 131277{\cdot}14 = 4862{\cdot}12$	+ 0·01
C = 6563·93	$\frac{1}{20} \times 131277{\cdot}14 = 6563{\cdot}86$	− ·0

[1] *C. R.* lxix. p. 694 (1869).

[2] *Phil. Mag.* xli. p. 291 (1871).

A few years ago Dr. Huggins succeeded in obtaining photographs of ten ultra-violet lines observed in the spectra of stars, which in the visible part give chiefly the hydrogen lines. These ultra-violet lines are most likely all due to hydrogen, and we know that this is the case with the four least refrangible ones. Mr. Johnstone Stoney has pointed out several harmonic ratios connecting them together; the hydrogen line $H\gamma$ near G, for instance, has a wave-length which is very nearly in the ratio of 35 : 32 with the one which is nearly coincident with the solar line H.[1]

Mr. Johnstone Stoney[2] has also examined the absorption spectrum of chlorochromic anhydride. The bands of that spectrum seem to be distributed with remarkable regularity. Mr. Stoney considers them to be all harmonics of one fundamental vibration. The measurements do not, however, seem to possess that degree of accuracy which is desirable, and can be obtained by our present methods. We must, therefore, suspend our judgment for the present on the reality of the coincidences pointed out by Mr. Stoney. Other writers, as, for instance, Soret,[3] have from time to time drawn attention to harmonic ratios in various spectra, and the author of this report[4] has during the last ten years collected a large quantity of material bearing on the question. The results have, on the whole, not been favourable to the theory of harmonic ratios. In any spectrum containing a large number of lines it is clear that, owing to accidental coincidences, we shall always be able to find ratios which agree very closely with the ratios of small integer numbers. It is only by means of a systematic investigation that we can find out whether these coincidences are due to any real cause. We must, by means of the theory of probability, calculate the number of the coincidences which we might expect to find on the supposition that the lines are distributed at random throughout the whole range of the visible spectrum. If on calculating out all fractions which can be formed in a spectrum by any pair of lines the number of ratios agreeing within certain limits with ratios of integer number greatly exceeds the most probable number, we should have reason to suppose that the lines are not distributed at random, but that the law suggested by Messrs. Lecoq de Boisbaudran and Stoney is a true one. The following two tables exhibit the results of an investigation which has been conducted on these lines.

TABLE II.

Element	Number of Fractions	Mean Value of Ratios	P = ±
Magnesium	18	·2626	·0229
Sodium	40	·2399	·0154
Copper	101	·2430	·0097
Barium	303	·2592	·0056
Iron	10404	·2513	·0010
Mean . . .	10866	·2514	—

[1] A photograph taken by Captain Abney shows conclusively, as has already been pointed out by Vogel, that the hydrogen line is a little less refrangible than H, and it is very likely coincident with the line 3969 ? which, according to Young, falls within the broad shadow of H, and is always present in the chromosphere.

[2] *Phil. Mag.* xlii. p. 41 (1871). [3] *Phil. Mag.* xlii. p. 464 (1871).

[4] *Proc. Roy. Soc.* xxxi. p. 337 (1881).

For the full explanation of Table II. we must refer to the paper which has already been quoted. The second column gives the number of fractions investigated for each element. The third column gives a number which ought to be nearly ·25 (probably within the limits of the values of the fourth column), if the lines are distributed at random and decidedly smaller than this number if the law of harmonic ratios is true.

It will be seen that three out of the five elements considered, including the two containing the greatest number of lines, give a mean value greater than ·25, and that in the two remaining cases the number, though smaller than ·25, falls within the limits into which we must expect it to fall, on the supposition of a distribution at random. Table III. shows the results of a more detailed examination of the iron spectrum, over 10,000 fractions having been calculated and compared with ratios of integers smaller than 100. In order to calculate the number of coincidences which we might expect on the theory of probability, the limits had to be fixed within which we may consider a coincidence to have taken place. These limits must of course depend on the accuracy which we assign to the measurements of the lines. The results were worked out for two different limits, which were $\pm$ ·0000505 and $\pm$ ·0000755. When, therefore, two lines had periods the ratio of which fell within the indicated limits of some ratio of two integer numbers smaller than 100, this was called a coincidence. In Table III. the columns headed 'Observed' and 'Calculated' give the number of these coincidences as actually found, and as calculated from the theory of probability. In the first row all fractions were taken into account the denominator of which is smaller than 10; in the second row the denominator is between 10 and 20, and so on for the other rows.

TABLE III.

	Limits, ± ·0000505		Limits, ± ·0000755	
	Observed	Calculated	Observed	Calculated
0–10 . . .	48	52	64	77
10–20 . . .	180	206	250	308
20–30 . . .	329	363	469	544
30–40 . . .	478	521	664	779
40–50 . . .	625	679	912	1015
50–60 . . .	777	837	1163	1251
60–70 . . .	886	968	1318	1447
70–80 . . .	924	896	1337	1340
80–90 . . .	667	629	989	·940
90–100 . .	253	241	393	361
Total . .	5167	5392	7559	8062

The result seems, again, decidedly against the theory of harmonic ratios. For all fractions with denominator smaller than 70 the calculated coincidences are in excess of the observed ones. There seems, however, to be a greater number of ratios than we should expect which agree nearly with fractions the denominators of which lie between 70 and 100.

If we compare the results given for the two different limits we find that the smaller limit gives results decidedly more favourable to the theory than the larger ones; and this is an important fact which cannot

be left out of account. For the full discussion of it we refer to the original paper, and only quote, in conclusion, the summary of results obtained:—

1. There is a real cause acting in a direction opposed to the law of harmonic ratios, so far as fractions formed by numbers smaller than 70 are concerned.

2. After elimination of the first cause a tendency appears for fractions formed by two lines to cluster round harmonic ratios.

3. Most probably some law hitherto undiscovered exists which in special cases resolves itself into the law of harmonic ratios.

It must be remarked, however, that these conclusions must stand at present on the evidence of the iron spectrum alone, and it is not impossible that the regularities which have been discovered are due to accident. We can at present only say that the investigation, as far as it has gone, seems to point to the above conclusions.

There is one fact which points very strongly to another yet undiscovered law which rules over the distribution of lines in spectra. It is often observed that the spectrum of some body contains two or three lines in close proximity, forming a characteristic group. Such doublets or triplets are often repeated several times in the spectrum; yet, though we might expect, if the harmonic law was true, to find some simple relations connecting the periods of these sets, such is not the case. The lines of sodium, for instance, are all double. In the set of lines given by Thalèn the components approach each other as we pass to the more refrangible end of the spectrum more rapidly than they would if the lines were connected by the harmonic law. In the following table the wave-length of the least refrangible of each set of sodium lines is given, together with the distance of the two components. In addition to the pairs observed by Thalèn, one pair in the ultra-red, photographed by Abney, and one pair in the ultra-violet, photographed by Cornu, are given.

TABLE IV.

8199	12	Abney
6160·0	5·8	Thalèn
5895·0	6	Thalèn
5687·2	5·8	Thalèn
5154·8	2·3	Thalèn
4982·5	Not resolved	Thalèn
3301·2	0·4	Cornu

Professors Liveing and Dewar[1] have observed some additional sets of double sodium lines, but the distance between the components of each pair does not seem to follow any law.

The spectrum of potassium as observed by Liveing and Dewar[2] contains, when the metal is heated in the electric arc, five groups of lines, each containing four lines. Though, roughly speaking, the lines of each set are the nearer together the shorter the wave-length of the set, there seems to be no general and well-defined law.

The most remarkable perhaps of all the groups of lines observed in the spectra of metals are the magnesium triplets. The well-known set of lines in the green is repeated three times in the ultra-violet; but Table V.

[1] *Proc. Roy. Soc.* xxiv. p. 398 (1879). [2] *Ibidem.*

shows that the resemblance is only a general one, and that the relative distances vary considerably in each set.

TABLE V.

Wave-length of least refrangible line	Distance from first to second line	Distance from second to third line	Observer
5183·1	10·9	5·3	Ångström
3837·6	6·2	2·4	Cornu
3334·2	4·2	3·0	"
3095·6	3·7	1·9	"

It will be noticed that the groups come nearer and nearer together as they approach the violet, and that also the lines in each group are the closer together the more refrangible the set. Roughly speaking, the distance between the first and second line of each set is proportional to the square of the wave-length; in order that this relation ought to hold rigidly, these distances for the ultra-violet sets ought to be respectively 7·5, 4·5, 3·9. Such a relation ought to hold if the lines are successive harmonics of one fundamental vibration, according to Stoney's supposition.

The fact that successive lines which belong to one vibrating system come nearer and nearer together as they approach the violet or ultra-violet end of the spectrum seems to be a pretty general one, and is well exemplified by the system of hydrogen lines which Huggins found in the star spectra. Table VI. gives the wave-lengths of the lines and their differences.

TABLE VI.

Hydrogen	Solar	Wave-length	Difference
Hα	C	6561·8	
Hβ	F	4860·6	1701·2
Hγ	Near G	4340·1	502·5
Hδ	h	4101·2	238·9
Hϵ	Near H	3969	132·2
Hζ		3887·5	81·5
Hη		3834	53 5
Hθ		3795	39
Hι		3767·5	27·5
Hκ		3745 5	22
Hλ		3730·1	15 5
Hμ		3717·5	12·5
Hν		3707·5	10·0
		3699	8 5

Huggins calls the line Hζ, a and continues with the alphabet towards the ultra-violet. This designation was chosen independently of the fact that the lines probably belonged to hydrogen. As the red hydrogen line usually is called Hα, we have continued the same nomenclature towards the ultra-violet. Hence the discrepancy with Huggins' designation.

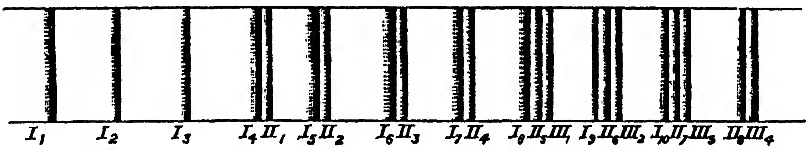
It has been pointed out by Johnstone Stoney that the second differences show greater irregularities than can be accounted for by errors of observation, and that therefore the system of lines does not altogether lie on a smooth curve when plotted down with wave-lengths as ordinates, the ordinates lying at equal intervals of each other. Nevertheless the fact that these lines approach each other rapidly, making up a fluting on a large scale, and that generally characteristic groups when repeated

several times come nearer and nearer together towards the ultra-violet, while at the same time the members of each group also approach, is very suggestive, and promises to furnish a safer basis for future research than the hypothesis of harmonic ratios. As another example illustrating the same fact, we may mention the absorption spectrum of iodine, where the distance of fluted bands of each set decreases with the wave-length.

There is one more fact which ought to be mentioned. The fluted bands in spectra are often at fairly equal intervals from each other, but a curious change and transformation seems sometimes to occur. Fig. 1 is not intended to represent any particular spectrum, but simply to represent this transformation; to the left a series of bands are seen which have been denoted by I_1, I_2, &c.; but to the right of I_4 springs up another faint band, II_1, which, being repeated, gradually gains in intensity until finally, by the side of II_8, the band of the first series is no longer visible.

A third series of bands, III_1, III_2, &c., springs up again to the right of the second series, and in its turn overpowers it in intensity. Those who are familiar with fluted band spectra will easily call back to their minds the single bands like I_1, the bands with weak companion like I_4, or the double and treble bands like I_7 or I_9. Thalèn has

Fig. 1.



pointed out how the absorption spectrum of iodine is composed of several such overlapping spectra. The bands in this case shade off towards the red, and the additional bands always spring up towards the violet. The bands approach each other very rapidly as they approach the violet end. The differences between corresponding bands of the second series are always smaller than between those of the first series, so that the distance between two adjacent bands of the first and second series becomes larger towards the red; the same holds good for the other series. Mr. Lockyer has noticed in his photographs of the spectrum, which appears in the electric arc and seems to be due to nitrocarbon, that the least refrangible of the ultra-violet bands does not seem to correspond with the least refrangible, but with the second band of the violet series, so that here, apparently, a similar change has taken place, an additional band having sprung up in the least refrangible side. It is much to be desired that such changes should be carefully examined in each case, as they may lead to most valuable results.

The tendency to form flutings is very remarkable. We have first the wide fluting formed by the hydrogen lines; we have next the narrow flutings of band spectra, and this again, as in the case of iodine gas, approaching each other indefinitely as they go towards the violet, seems to form a fluting of the second order—a fluting of flutings. In the overlapping bands of different series we may even recognise perhaps flutings of the third order.

II. *Relation of the Spectrum of an Element to that of its Compounds.*

There is perhaps no other investigation connected with molecular vibrations which is of greater interest than that which tries to trace the connection between the spectrum of an element and that of its compounds. It was at first considered, as has already been mentioned, that an element preserved its spectrum when entering into combination, so that, for instance, the oxide of a metal would only show the metallic lines except in so far as oxygen lines might be visible. This idea had to be given up, but the absorption spectra of fluids were considered at first to be evidence in favour of the assumption of permanence of the spectrum of an element when combined with others. We owe the first systematic investigation on this point to Dr. Gladstone,[1] who examined the absorption spectra of the solution of salts, each constituent of which was coloured. He came to the conclusion that, generally, but not invariably, the following law held good: 'When an acid and a base combine, each of which has a different influence on the rays of light, a solution of the resulting salt will transmit only those rays which are not absorbed by either, or, in other words, which are transmitted by both.'

Thus, for instance, chromic acid in solution cuts off the more refrangible half of the spectrum, admitting only the blue rays near F in thin solutions; but they transmit the less refrangible half perfectly. This characteristic absorption of chromic acid remains when the acid is combined with such bodies as copper, nickel, ferric oxide, uranium, potash, and chromium; but the salts formed by combination with the three first-mentioned bodies show also their own influence when combined with chromic or other acids by cutting off, as in copper and nickel, part of the red end of the spectrum, or extending, as in ferric oxide, the blue absorption into the green. The characteristic absorption bands of uranium salts are in the blue. As the chromic acid cuts off the blue, chromate of uranium will not show the bands, but only a general absorption in their stead. The potassium salts are colourless when combined with colourless acids, and chromate of potash shows therefore the same spectrum as chromic acid. Chromate of chromium forms an exception to the rule, for though the absorption peculiar to chromic acid exists, the absorption visible in ordinary chromium salts does not appear. Soret[2] has confirmed Dr. Gladstone's conclusions with regard to the identity of the absorption spectra of different chromates. The chromates of sodium, potassium, and amn.onia, as well as the bichromates of potassium and ammonia, were found to give the same absorption spectrum. Nor is the effect of these chromates confined to the blocking out simply of one end of the spectrum, as in the visible part, but two distinct absorption bands are seen, which seem unchanged in position if one of the above-mentioned chromates is replaced by another. These absorption bands show themselves only in weak solutions; the centre of one has a wave-length of about $3610\ 10^{-10}$ metres, while the other is wider, and reaches from 2950 to 2440 approximately in solutions containing about 0·1 grammes to the litre. From 2220 onwards the spectrum is completely blocked out. Chromic acid itself showed the bands, but less distinctly, and Soret does not consider the purity of the acid sufficiently proved to allow him to draw any certain conclusions from this observation.

[1] *Phil Mag.* xiv. p. 418 (1857).
[2] *Bibliothèque Universelle Arch. Sc. Ph.* lxi. p. 322 (1878).

Erhard[1] has examined the absorption spectra of some salts in whicl chromium plays the part of a base. It may be said as a general rule tha these salts absorb the yellow and yellowish-green and also the violet en(of the spectrum, transmitting the blue; the exact position of the maxi mum of absorption, however, and the intensity of the absorption band varies considerably with different salts, and even for the same salt witl different temperatures, and the results are complicated by the fact tha heating the salts produces a permanent alteration in the absorption. Th(insoluble chloride of chromium shows a behaviour differing from that o the other chromium salts. It transmits the yellow and more of the viole than the other salts. Some of the solid crystals of various chromiun salts show fine absorption bands in the red which can also be traced ii some of the solutions. There is therefore a general resemblance in th(absorption of different chromium salts, but no identity.

Dr. Gladstone has also examined the effect of chlorine, bromine and iodine when combined with different metals. The bromides of gold platinum, palladium, and potassium give a spectrum which is identica with that of bromine water; the same applies to a concentrated solutioı of the bromide of copper, which in addition shows the red absorptioı characteristic of copper. A dilute solution of bromide of copper shows however, no absorption which can be traced to the bromine. Similaı results were obtained with the chlorides and iodides. In pointing ou that it is generally though not universally true that a base or an acic retains its absorptive properties in different combinations, Dr. Gladston(draws attention to the remarkable exception of ferric ferrocyanide, whicl when dissolved in oxalic acid transmits blue rays in great abundance though the same rays are generally absorbed both by ferrocyanides anc by ferric salts.

Nitric acid and the nitrates of transparent bases such as potassium sodium, and ammonia show spectra, according to Soret, which are no only qualitatively but also quantitatively identical; that is to say, ɛ given quantity of nitric acid in solution gives a characteristic absorptioı band of exactly the same width and darkness whether by itself alon(or combined with a transparent base. It also shows a continuous absorp- tion at the most refrangible side, beginning with each of the mentioned salts at exactly the same point. The ethereal nitrates,[2] however, give different results.

Messrs. Hartley and Huntington have by photographic methods examined the absorption spectra of a great number of organic compounds. As their researches have already been referred to at length in these reports,[3] by one of the authors, we need at present only mention one oı two of the results which most interest us from our present point of view. The normal alcohols were found to be transparent for the ultra-violet rays, the normal fatty acids less so. In both cases an increased numbeı of carbon atoms increases the absorption at the most refrangible end. The fact that benzene and its derivatives are remarkable for their power- ful absorption of the most refrangible rays, and for characteristic ab- sorption bands appearing on dilution, led Professor Hartley to a more extended examination of some of the more complicated organic substances. He came to the conclusion that definite absorption bands are only pro-

[1] *Inaugural Dissertation*, Freiburg (without date).
[2] *Brit. Ass. Rep.* 1880, p. 55. [3] *C. R.* lxxxix. p. 747.

duced by substances in which three pairs of carbon atoms are doubly linked together, as in the benzine ring.

In most of the cases which we have hitherto discussed, the characteristic absorption of the substance under examination extended over a considerable range; the substance either blocked out altogether a large part of the spectrum, or at least showed absorption bands which were broad and increased considerably in width with increased concentration. When, however, absorption bands become narrower and more definite, so that they can be examined under high dispersive powers, their behaviour under different circumstances becomes more interesting, for we can trace smaller differences and more minute changes.

It was Bunsen[1] who first showed that such small changes do occur, and he thereby led the way in a line of research which promises to be of great importance. While examining the absorption spectra of different didymium salts, he found that though all the salts showed spectra so nearly identical that with the ordinary one prism spectroscope they could easily be mistaken for each other, higher dispersive powers revealed some very interesting and characteristic changes. His conclusions are best quoted in his own words:—

'Very remarkable and noteworthy are the small alterations in position which occur in the minima of brightness in the didymium spectrum, dependent upon the nature of the compound in which the metal occurs. These changes are too minute to be seen with the small, though seen with the large instrument. I have as yet only investigated them completely in the case of three didymium salts, viz., the chloride, sulphate, and acetate. It is, however, more than probable that the same phenomena will also be found to occur with other solutions, and with the absorption spectra of other crystals of didymium salts, and perhaps may be exhibited with the luminous spectra of the oxide and other compounds of didymium. . . . . The atomic weight of didymium chloride is 95·9, and that of the anhydrous acetate is 106·9. It will be noticed that all the groups of bands in the case of salts under examination approach the red end of the spectrum in the order of their increasing atomic weights.

'These differences here noticed in the absorption spectra of different didymium compounds cannot in our present complete state of ignorance of any general theory for the absorption of light in absorptive media be connected with other phenomena. They remind one of the slight and gradual alterations in pitch which the notes from a vibrating elastic rod undergo when the rod is weighted, or of the change of tone which an organ-pipe exhibits when the tube is lengthened.'

The increased lowering of the vibrations with increasing atomic weight of substance combined with the didymium is no doubt very suggestive, but we cannot at present assign any definite law regulating the displacement in different cases. Thus the difference in the wave-length between the bands of the chloride and acetate is nearly the same for all four bands, but the difference in the wave-length between the bands of the chloride and acetate decreases rapidly with decreasing wave-length, so that the yellow band is displaced about twice as much as the green band, and about three times as much as the bands in the blue. It follows from this difference in the behaviour that while the effect of the acetate on the yellow band is about seven times as large as that of the sulphate,

[1] *Phil. Mag.* [4] xxxii. p. 177.

the effect is only about twice as large on the blue band. We must refer to a note by Messrs. Lawrance Smith and Lecoq de Boisbaudran [1] for a description of the spectrum of the nitrate of didymium and its changes on addition of nitric acid.

Some interesting cases of this shifting of bands in different compounds of the same body have been found by Professor Russell,[2] who has subjected the cobalt salts to a very careful and most instructive examination. The anhydrous bromide of cobalt, for instance, was found to give an absorption spectrum strongly similar to that of the chloride, but there is a general displacement of all the bands towards the red corresponding to the increased atomic weight of bromine. The effect on the most refrangible band is stronger than that on the other two bands, which is contrary to what Bunsen has observed in the case of didymium acetate.

Captain Abney and Lieutenant-Colonel Festing's paper[3] 'On the Influence of the Atomic Grouping in the Molecules of Organic Bodies on their Absorption in the Infra-red Region of the Spectrum,' contains an account of investigations undertaken to throw light on the effect of chemical combination on molecular vibrations. The importance of the results which they have obtained will justify a few verbal quotations. They distinguish a general absorption from the least refrangible end, and special absorptions which may consist of lines or bands.

'Regarding the general absorption we have nothing very noteworthy to remark, beyond the fact that, as a rule, in the hydrocarbons of the same series those of heavier molecular constitution seem to have less than those of lighter.'

This effect agrees with the observation made by Professors Hartley and Huntington in the ultra-violet in so far as a general shifting of the absorption towards the red seems to take place as the number of carbon atoms is increased. Such a shifting would increase the general absorption in the ultra-violet, as observed by Professors Hartley and Huntington, and decrease it in the infra-red, as observed by Captain Abney and Colonel Festing. Turning their attention next to the sharply defined lines, our authors, by means of a series of systematic experiments, come to the conclusion that these must be due to the hydrogen atoms in the molecule.

'A crucial test was to observe spectra containing hydrogen and chlorine, hydrogen and oxygen, and hydrogen and nitrogen.

'We therefore tried hydrochloric acid and obtained a spectrum containing some few lines. Water gave lines, together with bands, two lines being coincident with those in the spectrum of hydrochloric acid.

'In ammonia, nitric acid, and sulphuric acid we also obtained sharply-marked lines, coincidences in the different spectra being observed, and nearly every line mapped found its analogue in the chloroform spectrum, and usually in that of ethyl iodide. Benzene again gave a spectrum consisting principally of lines, and these were coincident with some lines also to be found in chloroform. It seems then that the hydrogen, which is common to all these different compounds, must be the cause of the linear spectrum. In what manner the hydrogen annihilates the waves of radiation at these particular points is a question which is at present, at all events, an open one, but that the linear absorptions, common to the hydrocarbons and to those bodies in which hydrogen is in combination

[1] *C. R.* lxxxviii. p. 1167 (1879). [2] *Proc. Roy. Soc.* xxxii. p. 258 (1881).
[3] *Phil. Trans.* p. 887 (1881, iii.).

with other elements such as oxygen and nitrogen, is due to hydrogen, there can be no manner of doubt.'

. . . .

'The next point that required solution was the effect of the presence of oxygen on the body under examination, and here we had ample material on which to make our observations. It appears that in every case where oxygen is present, otherwise than as a part of the radical, it is attached to some hydrogen atom in such a way that it obliterates the radiation between two of the lines which are due to that hydrogen.' . . . 'If more than one hydroxyl group be present, we doubt if any direct effect is produced beyond that produced by one hydroxyl group, except a possibly greater general absorption; a good example of this will be found in cinnamic alcohol and phenyl-propyl alcohol, which give the same spectra as far as the special absorptions are concerned. . . .

'Hitherto we have only taken into account oxygen which is not contained in the radical; when it is so contained it appears to act differently, always supposing hydrogen to be present as well. We need only refer to the spectrum of aldehyde, which is inclined to be linear rather than banded, or rather the bands are bounded by absolute lines, and are more defined than when oxygen is more loosely bonded.'

Perhaps the most interesting passage is that which refers to the detection of the radical, and we therefore quote it in full.

'An inspection of our maps will show that the radical of a body is represented by certain well-marked bands, some differing in position according as it is bonded with hydrogen, or a halogen, or with carbon, oxygen, or nitrogen. There seem to be characteristic bands, however, of any one series of radicals between 1000 and about 1100, which would indicate what may be called the central hydrocarbon group, to which other radicals may be bonded.

'The clue to the composition of a body, however, would seem to lie between λ 700 and λ 1000. Certain radicals have a distinctive absorption about λ 700 together with others about λ 900, and if the first be visible it almost follows that the distinctive mark of the radical with which it is connected will be found. Thus in the ethyl series we find an absorption at 740, and a characteristic band, one edge of which is at 892, and the other at 920. If we find a body containing the 740 absorption and a band with the most refrangible edge commencing at 892, or with the least refrangible edge terminating at 920, we may be pretty sure that we have an ethyl radical present. So with any of the aromatic group; the crucial line is at 867. If that line be connected with a band we may feel certain that some derivative of benzine is present. The benzyl group show this remarkably well, since we see that phenyl is present, as is also methyl. It will be advantageous if the spectra of ammonia, benzine, aniline, and dimethyl aniline be compared, when the remarkable coincidences will at once become apparent, as also the different weighting of the molecule. The spectrum of nitro-benzine is also worth comparing with benzine and nitric acid. We should have liked to have said more regarding the detection of the different radicals, but it might seem presumptuous on our part to lay down any general law on the results of the comparatively few compounds which we have examined. In our own minds there lingers no doubt as to the easy detection of any radical which we have examined, but it will require more energy and ability than we possess to thoroughly classify all the different modifications which may arise.

'We may say, however, it seems highly probable by this delicate mode of analysis that the hypothetical position of any hydrogen which is replaced may be identified, a point which is of prime importance in organic chemistry.

'The detection of the presence of chlorine or bromine or iodine in a compound is at present undecided, and it may well be that we may have to look for its effects in a different part of the spectrum. The only trace we can find at present is in ethyl bromide, in which the radical band about 900 is curtailed in one wing. The difference between amyl iodide and amyl bromide is not sufficiently marked to be of any value.'

If we compare the results obtained by Captain Abney and Colonel Festing with those arrived at by Professor Russell and others in the visible part of the spectrum, we are struck with the great persistency of these infra-red bands and lines. Spectra of different compounds of the same body may resemble each other in the visible part, but wherever the absorption band or line was sufficiently narrow to be looked at under high dispersion some difference made itself apparent, like the one discovered by Bunsen in the case of didymium compounds. These differences are generally sufficiently large to be noticed even with one prism when proper care is taken. It would seem very remarkable if atoms could enter into combination with their vibrations unchanged by the chemical force; though, of course, the change may be more apparent in some parts of the spectrum than in others. Whether the infra-red bands are not affected at all, or whether only the change is so small that it has not as yet been discovered, is an open question. Our prismatic methods would, of course, discover more easily a shift in the visible part than in the infra-red, but Captain Abney and Colonel Festing used three prisms, and there can be no doubt that if the displacements had been of the same order of magnitude as they are with the didymium, and especially the cobalt salts, they could not have escaped detection.

Alexr. Mitscherlich[1] was the first to prove that compound bodies, when luminous, have a spectrum of their own, and do not simply show the supposed spectra of the elements. He followed up this important discovery by investigating the spectra of different compounds of the same metal, and he could not fail to be struck with the similarity which such spectra often present.

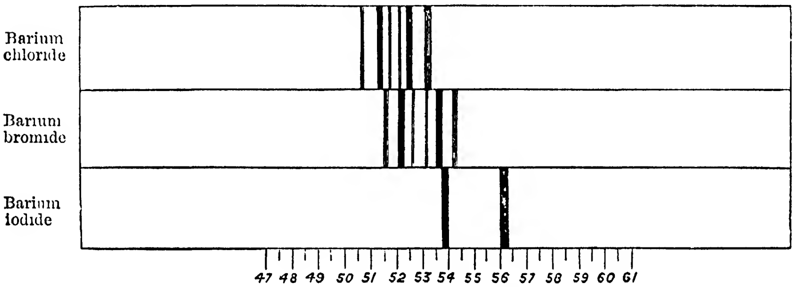
Many, for instance, will instantly recognise the spectrum of the oxide or chloride of calcium as that of a calcium compound, without being even aware that these spectra present certain well-marked differences. Comparing together the spectra of the fluoride, chloride, bromide, and iodide of barium, as they appear on Mitscherlich's map, we detect at once a strong similarity; we seem to have one spectrum shifted towards the red with increasing atomic weight of the metalloid. At the same time the least refracted bands seem to be most affected and, as a consequence, the bands appear nearest together in the fluoride and farthest apart in the iodide. In the calcium and strontium salts we notice the same increase of wave-length in corresponding bands with increasing atomic weight, but with these two metals the most refracted bands are most affected, so that the bands are the nearer together the higher the atomic weight. Mitscherlich tried to find a numerical expression for these relations, and he expresses the law which, according to his observation, represents the facts, in the following way:—

[1] *Pogg. Ann.* cxvi. p. 499.

'It follows that in the haloid compounds of barium (excepting the fluoride) the distance between corresponding spectral lines is directly proportional to the atomic weight, and that in the haloid compounds of calcium and strontium (excepting again the fluoride) these distances are inversely proportional to the atomic weights. Further, that there is such a point in the spectrum of each metal that the bands keep their relative distances from it in the different compounds. Here also we must except the fluorides.'

Mitscherlich's measurements were not sufficiently accurate to prove his statement satisfactorily, but we can easily test it by means of the more exact measurements of Lecoq de Boisbaudran, who has carefully mapped the spectra of the chloride, bromide, and iodide of barium. A glance at Fig. 2, which represents these spectra according to Lecoq's

Fig. 2.



measurements will show their similarity. In Table VII. the first column gives the wave-length of the bands seen in the spectrum of the barium chloride. The strongest band is denoted by α, and the order of the Greek letters gives the order of the intensity. In the second column a comparison is given between the observed wave-lengths of the spectrum of barium bromide, and the same wave-lengths calculated on Mitscherlich's supposition that the distance between the lines is proportional to the atomic weight of the compound. The band α is taken as starting point. The third column gives the calculated value for the band β of barium iodide, which compound only shows α and β.

TABLE VII.

Barium Chloride	Barium Bromide		Barium Iodide	
Observed	Calculated	Observed	Calculated	Observed
γ 5313	5459	5410		
α 5242		5358		5607
δ_1 5205	5303	5304		
δ_2 5171	5257	5249		
β 5136	5207	5206	5408	5376
ϵ 5064	5105	5149		

It will be seen that for the four central bands of barium bromide the agreement seems good, but the two outer bands do not follow the rule,

for the distance between α and γ and between β and ε is actually larger in the chloride than in the bromide, contrary to what holds for the remaining bands. In the case of barium iodide, Mitscherlich's rule cannot be said to hold.

A more satisfactory agreement could be obtained if the distances between the corresponding bands were made to depend, not on the atomic weights of the compound, but on the atomic weights of the metalloid in the compound; but no object is gained at present by giving such rules before sufficient material has been accumulated to prove or disprove them. The second part of Mitscherlich's rule, which regulates the displacement of the bands in the different compounds, does not stand very well when tested by Lecoq's measurements; the band β of barium iodide, for instance, ought, according to it, to be at 5356 instead of 5376.

We ought to inquire whether a connection can be traced between the lines of a metal and that of one of its compounds. It would be possible, for instance, that the oxide should show its bands chiefly at such places at which we find lines in the metallic spectrum, and such a rule might be suggested by the examination of the calcium spectrum, which shows a characteristic group of lines exactly at the place which is filled by the green band of the oxide. No general rule can, however, be given, and in some cases even the metallic spectrum seems particularly free of lines in or about the place in which we find the oxide bands. There is at present no hope whatever of directly connecting the spectrum of a metal and that of its compounds, though, as was seen, we may hope to gain an insight into the relations of the spectra of such similar compounds as the chlorides, bromides, and iodides, which may be supposed to have a similar constitution.

Some very interesting changes have been noticed in the position of absorption bands when certain colouring matters are dissolved in different liquids. We mention the names only of Hagenbach, Kraus, and Kundt as having studied the question in particular cases. Two papers by Kundt[1] and Claes[2] contain all that is known at present on the subject, and it will be sufficient therefore to consider them only. Kundt examined the position of the absorption bands of chlorophyll, anilingreen, cyanin, fuchsin, chinizarin, and of the colouring matter of the yolk of egg when dissolved in a number of liquids. His results are given in Table VIII., which is taken out of his paper. The solvents are arranged in each column in such order that with the one first on the list the absorption band is seen most towards the blue, while the one which appears last displaces the band most towards the red.

In the dissertation published by Dr. Claes we must carefully distinguish the experimental from the theoretical part. We have at present no reason to doubt the accuracy of his experimental work, and as he used solvents and liquids partly different from those employed by Professor Kundt, we give his results in Table IX. arranged in the same way as Table VIII. We give the results for chlorophyll in two columns; one refers to the absorption band in the red, the second to the absorption bands in the green. Magdala red shows different absorption bands in two different sets of solutions, and two columns are therefore also necessary. The results obtained with different didymium compounds are not tabulated, as they are partly due to a different order of phenomena.

[1] *Wied. Ann.* iv. p. 34 (1878). [2] *Wied. Ann.* iii. p. 389 (1878).

TABLE VIII.

Chlorophyll	Anilingreen	Cyanin	Fuchsin	Chinizarin	Yolk of egg
Ether	Methyl-alcohol	Methyl-alcohol	Water	Methyl-alcohol	Methyl-alcohol
Aceton	Aceton	Aceton	Methyl-alcohol	Aceton	Aceton
Alcohol	Alcohol	Alcohol	Aceton	Ether	Ether
Amyl-alcohol	Ether	Ether	Alcohol	Alcohol	Alcohol
Chloroform	Chloroform	Amyl-alcohol	Ether	Amyl-alcohol	Amyl-alcohol
Benzine	Amyl-alcohol	Ligroin	Chloroform	Chloroform	Ligroin
Oil of Cassia	Ligroin	Chloroform	Amyl-alcohol	Toluol	Chloroform
Bisulphide of carbon	Toluol	Toluol	Ligroin	Benzine	Toluol
	Benzine	Benzine	Benzine	Oil of cassia	Benzine
	Oil of cassia	Oil of cassia	Toluol	Bisulphide of carbon	Oil of cassia
	Bisulphide of carbon	Bisulphide of carbon	Oil of cassia		Bisulphide of carbon
			Bisulphide of carbon		

In a preliminary examination,[1] Professor Kundt had come to the conclusion that solvents displaced absorption bands towards the red in the order of their dispersive powers. A look at Table VIII. will show that no absolute rule, however, can be given, for the order of the solvents

TABLE IX.

Chlorophyll		Cyanin	Chinizarin	Fuchsin	Eosin	Magdala red	
I.	II.					I.	II.
Ether	Ether	Alcohol	Alcohol	Water	Water	Nitrobenzine	Benzine
Alcohol	Alcohol	Ether	Ether	Alcohol	Alcohol	Alcohol	Bisulphide of carbon
Nitrobenzine	Benzine	Benzine	Turpentine	Nitrobenzine	Turpentine	Turpentine	
Benzine	Nitrobenzine	Nitrobenzine	Benzine		Bisulphide of carbon		
Turpentine	Turpentine	Bisulphide of carbon	Nitrobenzine		Nitrobenzine		
Bisulphide of carbon	Bisulphide of carbon		Bisulphide of carbon				

is different for different colouring matters. At the same time it is certainly remarkable that the liquids of high dispersive powers always stand at the bottom of the list, while those of low dispersive powers stand high up. Professor Kundt therefore now replaces his old conclusion by the less definite rule that 'When a colourless solvent has a considerably larger dispersive power than another the absorption band of a colouring

[1] Poggendorff, *Jubelband.*

matter dissolved in it is placed more towards the red.' He divides the solvents into four groups. While the order of the liquids within each group may change, the second group will always displace the absorption band more towards the red than the first, the third more than the second, and the fourth more than the third. Dr. Claes, who also remarks that the order of the solvents is not strictly that of their dispersive powers, suggests a formula which shall correctly represent the position of the absorption bands in different liquids. If λ is the wave-length of the centre of an absorption band, his equation, when freed from the sheltering confusion of ornamental variables, runs thus—

$$\lambda^2 - b = \alpha + \frac{\beta}{\lambda^2 - b} \quad . \quad . \quad . \quad . \quad (1)$$

In this equation b represents the dispersive constant of the liquid; that is to say, the factor of the inverse square of the wave-length in the series which gives the refractive index as a function of the wave-length; and α, β are two constants which, according to Dr. Claes, have to be determined for each absorption band by means of its position in different liquids. Now to ordinary minds the above equation seems simply a restricted case of Kundt's original law that the wave-length increases with the dispersive power, for we can solve for $\lambda^2 - b$, and this quantity must therefore be a constant, which, on the face of it, it is not, as Dr. Claes himself takes some pains to prove. Yet our author shows how the same law in its new shape can with astonishing accuracy explain facts which to most minds show no regularity at all. As it is a point of some importance to possess a method of calculation which shall give such small differences between observed and calculated values as those obtained by Dr. Claes, we may take the trouble to point it out, especially as he might have still further reduced these differences had he been more careful in his calculations with the two last decimal places. The secret consists in substituting in the expression on the right-hand side the observed values of λ and then calculating the λ on the left side. The differences between these two values Dr. Claes calls the differences between the observed and calculated values of λ. It is easy to see how this plan works. Write Λ for $\lambda^2 - b$, and call the values which Λ takes in the two special cases L_1 and L_2; then in the way suggested by the author α and β have to be determined in terms of L_1 and L_2, and by substituting these values equation (1) becomes

$$\Lambda = L_1 + L_2 - \frac{L_1 L_2}{\Lambda} \quad . \quad . \quad . \quad . \quad (2)$$

If we write $L_1 + d$ for the observed value of Λ we get

$$\Lambda - L_1 = L_2 - \frac{L_1 L_2}{L_1 + d} = \frac{d.L_2}{L_1 + d}$$

But the difference between $\Lambda - L_1$ and d being the so-called difference between the observed and calculated value becomes $\dfrac{d(L_2 - L_1) - d^2}{L_1 + d}$. As the total displacement $L_2 - L_1$ between any two bands is small, as well as d, this quantity is small compared to d. In other words, as long as Λ, L_1 and L_2 differ by small quantities, equation (2) must necessarily be true to quantities of the same order of magnitude, and any discrepancy must

be of the second order of magnitude. It is needless to enter further into the matter, but it is easily seen how fictitious the whole investigation of Dr. Claes now becomes.

Returning for a moment to the general law discovered by Kundt, that the displacement of bands depends to a greater extent on the dispersive power of the solvent than on any other of its properties, we may, perhaps, suggest the way in which such a result might be brought about. The refractive index of a liquid does not seem to be directly connected with the vibrations of its molecules, for we speak of the refractive index of waves which are infinitely long, and connect it with the inductive capacity which has nothing to do with vibrations. It is otherwise with the dispersion; we know that the very colouring matters which are most sensitive as far as the displacement of bands is concerned, show the so-called anomalous dispersion, which only means that the nearness of an absorption band causes an abnormally great dispersion at that point. If we are allowed to reason backwards and connect a great dispersive power at one place with a great coefficient of absorption at some point which is not too far removed, we might easily understand how these vibrations would in their turn affect the vibrations of the colouring matter and change their period. For it is a perfectly general rule that any spectroscopic disturbance, such as the widening of bands or appearance of high temperature lines, is more easily produced by molecules which vibrate in similar periods than by others,[1] and a solvent the molecules of which can vibrate in similar periods to that of the colouring matter will, no doubt, produce a displacement of bands towards the less refrangible regions. It is true that the high dispersion of some liquids—such as carbon bisulphide—has not been traced to the influence of any specific absorption, but even if, as is very likely, the above explanation is not strictly correct, we seem to have in the vibrations of the solvent a connecting link between the dispersion of a liquid and the displacement of bands which it is capable of producing. On the other hand it is easy to see why no perfectly general rule can be given; for the influence of the solvent will not only depend on the vibration of its molecules but also on the closeness of the connection between them and the molecules of the colouring matter. If there is any great affinity between the solvent and the colouring matter we should expect a great influence, and if the two bodies simply mix without troubling much about each other we should have no displacement at all, or only a very small one. The displacement of bands according to this view is due then, in the first instance, to the closeness of the chemical relation between solvent and colouring matter; and, secondly, to the similarity of their vibrations. If the dispersive power of a liquid enters into the question it can only be owing to the fact that the vibrations of the luminiferous medium and those of the colouring matter are similarly affected by the periods in which the molecules of the solvent are capable of vibrating.

It is proved by some experiments made by Professor Russell[2] that the shifting of bands can also be produced by solution in a solid body. Professor Russell has proved that when chloride of cobalt is fused together with potassic chloride it gives a certain absorption spectrum, which may be obtained with small displacements of bands when the potassic chloride

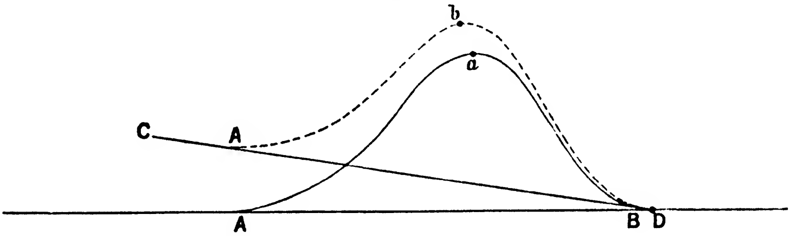
[1] *Cf.* a passage in a lecture by the author of this report before the Royal Institution.

[2] *Proc. Roy. Soc.* xxxii. p. 258 (1881).

is replaced by the chlorides of sodium, ammonia, or zinc. The bands are nearest the red with potassic chloride, and nearest the blue with zinc chloride.

Before leaving this part of the report, we may just refer to some experiments made by Professor Melde[1] to decide the question whether two coloured liquids have the positions of their absorption bands altered when mixed together. He found indeed that such an effect could be observed, but all his experiments admit of an obvious explanation. To take an ideal case, suppose in Fig. 3 the absorption of a liquid for different waves of light to be graphically represented by the curve A*a*B, with a maximum at *a*, and suppose this liquid to be mixed with another whose curve of absorption is represented by CD, the simple addition of the two curves will produce a third curve CA^1*b* D with a maximum at *b*. This maximum is obviously not in the same position as before, but takes place at a wave-length at which the two tangents to the two original curves are inclined equally but in opposite directions. All the somewhat complicated rules deduced by Professor Melde are easily explained in this way, and he would have observed exactly the same phenomena if he had put his two liquids in front of each other instead of mixing them together.

Fig. 3.



III. *Relations of the Spectra of different Elements.*

Various efforts have been made to connect together the spectra of different elements. The attempts in this direction generally assume that certain lines in one spectrum correspond to certain lines in another spectrum, and the question is raised whether the atom with the higher atomic weight has its corresponding lines more or less refrangible. In the opinion of the writer of this report no definite judgment can as yet be given as to the success of these efforts; some of the relations traced no doubt are interesting and deserve further attention, but most of them are far-fetched, and will very probably be proved to have no foundation in fact. Lecoq de Boisbaudran[2] has led the way in these speculations, and some of the similarities in different spectra pointed out by him are certainly of value. But whether his conclusion, that 'the spectra of the alkalies and alkaline earths, when classed according to their refrangibilities, are placed as their chemical properties in the order of their atomic weights,' will stand the test of further research, remains to be seen. Lecoq begins by comparing together the spectra of potassium and rubidium, as well as those of calcium, strontium, and barium. The spectrum both of potassium and rubidium begins, when heated up in the Bunsen burner, with two red lines; then follow, in the case of potassium,

[1] *Pogg.* cxxiv. p. 91 (1865), and cxxvi. p. 264. [2] *C. R.* lxix. pp. 445, 606, 657.

a group of three yellow rays, four green bands, and a line in the yellowish-green (only visible in the spark). In the case of rubidium these are replaced by a group of four red rays and four double lines in the yellow and green. The spectrum of potassium ends with a violet line, since proved to be double, and the spectrum of rubidium, as is known, also ends with two violet lines. If we form the ratio of the wave-length of the centre of each of the five intermediate groups in rubidium to those of the corresponding group in the potassium spectrum, we obtain the numbers 1·064, 1·065, 1·056, 1·058, 1·063, which numbers are approximately constant. The ratio of the middle of the two red rubidium lines to the middle of the two red potassium lines is 1·022, and the corresponding ratio of the violet lines is 1·04. If we accept the fact of correspondence of these lines we see that the atom with the higher atomic weight vibrates more slowly. The weak point of the comparison consists at present in the uncertainty as to which of all these lines and bands belong to the metal and which to the oxide. We could not of course attempt any correspondence between lines of the oxide of one metal and the lines of the other metal itself. Similar relations exist, according to Lecoq, between the two spectra we have discussed and that of calcium. The two blue calcium lines concluding the spectrum are again less refrangible than the two corresponding rubidium lines, and at the same time they are wider apart. There is, therefore, a progressive change, as pointed out by Lecoq, in the behaviour of these blue and violet lines, which in every case are truly metallic. In potassium they are very close together and in the violet; in rubidium they are wider apart and less refrangible, though still in the violet; in calcium they are still wider apart, and in the blue. If we connect this fact with the similar change which, as we have pointed out, sometimes occurs in one and the same spectrum, where double and triple lines go closer and closer together as they approach the violet, we seem certainly to have a suggestive analogy which may serve as the basis for further inquiries.

We shall only follow Lecoq into his comparison between the spectra of the chlorides of the alkaline earths, as his comparison of the metallic and oxide lines seems to be uncertain.

Both the spectrum of the chloride of calcium and that of strontium consists of five bands. The differences between the bands of the chloride of calcium gradually decrease; they become more refrangible; and the same holds for the four least refrangible bands of the spectrum of strontium chloride. Forming the proportion between the wave-lengths of corresponding bands we find that the ratios of the bands of strontium chloride to those of the calcium salt are 1·063, 1·065, 1·066, 1·070, 1·071, and these ratios are seen to increase gradually with the decrease of wave-lengths. The salt with the higher atomic weight vibrates, again, more slowly. The spectrum of barium chloride resembles in its general arrangement that of the strontium salt, but it has six bands instead of five, the central band being apparently broken up into two. Other discrepancies are noticed on further inspection, and the barium bands, contrary to the rule given by Lecoq, are more refrangible than those of the lighter metals. Lecoq gets out of the difficulty by supposing that the barium chloride spectrum which we observe is not the one corresponding to that of the strontium and calcium chloride, but that it is its higher harmonic, and that we are to look in the ultra-red for the true correspondence in the barium spectrum. This explanation may be correct, and

now that, thanks to Captain Abney, we may photograph in the ultra-red, we may test its truth; but we must observe that, if we once allow ourselves to take these harmonics to aid, we may arrange all our spectra in any order we like, for we need only assume that those which do not fit are higher or lower harmonics of the true spectrum. As they stand the spectra of the chlorides of barium, strontium, and calcium, though showing certain characteristic analogies, do not bear out Lecoq's theory.

Ditte[1] has tried to find an analogy between the spectra of sulphur, selenium, and tellurium, and to establish that the spectrum is displaced towards the blue as we go from the metalloid to the metal, that is to say, from the lighter to the heavier element. An inspection of the spectra in question has not led the author of this report to confirm this statement. The spectrum of selenium seems more contracted than the spectrum of sulphur, but we cannot recognise clearly any displacement towards the red or towards the blue. The spectrum of tellurium seems, if anything, more to the red than that of the other two metals.

Messrs. Troost and Hautefeuille[2] have compared the spectra of carbon, boron, silicium, titanium, and zirconium, and they also come to the conclusion that from the metalloid to the metal the spectrum seems progressively to move towards the blue.

As far as the first three bodies are concerned the relation seems, at first sight at any rate, to have some foundation, for we have here to deal with three spectra which, on the whole, resemble each other in appearance, and which seem to be displaced according to the suggested law.

Ciamician[3] has compared together the spectra of chlorine, bromine, and iodine. His experiments seem well conducted, and we therefore give his conclusions, reserving, however, every opinion as to the degree of certainty with which they have been established. It requires a much more careful experimental examination than even Ciamician has given to them to arrive at any proof of the reality of these analogies. The spectra in question are so variable with density and temperature that we cannot at present say whether we have to deal with a superposition of different spectra or simply a variation of relative intensity due to temperature. Some of Ciamician's analogies do not seem, certainly, to be very apparent, but the following conclusion is entitled to a place in this report:—

'The spectrum of vapour of bromine at low pressures becomes the more nearly like that of chlorine the smaller the pressure, while the spectrum of condensed bromine more nearly resembles the spectrum of iodine. Iodine, on the other hand, gives a spectrum resembling that of bromine at moderate pressures only; at very low pressures an analogy with the chlorine spectrum takes preponderance over that with the bromine spectrum. The spectrum of highly condensed iodine vapour cannot well be compared with that of the other two bodies. Chlorine, when it is highly condensed, gives a spectrum resembling that of bromine at large pressures and of iodine at moderate pressures; while at low pressures the spectrum of chlorine has no analogy to that of the other two elements.

'If we collect together for each body *all* the lines which appear separately under different circumstances, we can establish a complete correspondence between the lines of the three complete spectra.'

[1] *C. R.* lxxii. p. 622 (1871). [2] *C. R.* lxxii. p. 620 (1871).
[3] *Wien. Ber.* lxxviii. (1878).

The complete spectrum of iodine is placed most towards the blue, that of chlorine is placed most towards the red end of the spectrum.

In a subsequent paper Ciamician deals further, and we believe more successfully, with the question. He begins by examining the spectra of the carbon compounds. The spectrum of cyanogen consists of two sets of bands, one in the red and one in the blue; the bands in the red resemble the nitrogen bands, the bands in the blue resemble the carbon bands (candle spectrum). Ciamician therefore suggests that the bands in the red are due to the nitrogen atoms in the cyanogen molecules, while the bands in the blue are due to the carbon within the same molecule. There can be no doubt as to the correctness of the resemblance pointed out by Ciamician, and the only argument which can be urged against his conclusion is the uncertainty that both sets of bands belong to the same compound of carbon and nitrogen. There are some reasons for supposing that they are not; but as yet this is an open question. The spectrum of carbonic oxide is very similar to that of the carbon (candle spectrum), as has often been shown.

Ciamician makes a bold use of the division of the cyanogen spectrum into two halves, which, as just pointed out, resemble the spectra of nitrogen and carbon respectively. For he thinks that we can divide the spectra of some of the elements similarly into two parts, one part resembling the spectrum of one, the other part resembling the spectrum of a second element, and this division he suggests may be due to the fact that such an element is really a compound body, which is composed of the two elements to whose spectrum its own is analogous. The high temperature spectrum of silicium consists of a series of lines. The most refrangible half of the lines certainly resembles in its general arrangement to a marked degree the lines of carbon. The less refrangible lines Ciamician believes to resemble some of the oxygen lines, but this analogy does not appear very strikingly in the map which accompanies his paper. Silicium at low temperatures shows bands which, as pointed out by Messrs. Troost and Hautefeuille are very much like the carbon bands. Ciamician has also for the first time succeeded in obtaining two spectra of boron. Both the band and the line spectrum show a striking resemblance to the carbon spectra. The line spectrum of aluminium resembles in its most refrangible half also that of carbon, while its less refrangible half resembles the less refrangible half of silicium. The complete similarity of the spectra of aluminium and silicium, and that likeness of their most refrangible parts with the complete spectra of carbon and boron is the most striking analogy which has as yet been pointed out; but it ought perhaps to be added that Ciamician's drawing of the boron spectrum does not altogether tally with the account given by Messrs. Troost and Hautefeuille. The line spectrum of magnesium also shows a likeness to the line spectrum of carbon; and the carbon bands (candle spectrum) resemble certain bands seen in the spectrum of magnesium under certain circumstances, which according to Liveing and Dewar always involve the presence of hydrogen.[1]

[1] An example may here be given as to the misunderstandings which may arise owing to the confusion which reigns at present in spectroscopic nomenclature. Messrs. Dewar and Liveing have pointed out the resemblance of the hydrocarbon spectrum and the hydrogen-magnesium spectrum (*Proc. Roy. Soc.* xxx. p. 161, 1880). Ciamician writes that he also discovered the resemblance; but what Ciamician calls the hydrocarbon spectrum is an altogether different spectrum, presenting no resem-

The likeness of the spectra of calcium and strontium to the spectrum of magnesium is not so apparent, but Ciamician traces it in taking account only of the low temperature lines of strontium and calcium. The complete spectra of calcium, strontium, and barium are also homologous according to Ciamician—that is to say, we can find in each spectrum groups of lines corresponding to each group in the other two spectra. But the comparison seems less certain, for in spectra having such a large number of lines a little ingenuity will always discover certain likenesses. We do not mean to imply that the resemblances pointed out by Ciamician are imaginary, but only that spectra containing many lines ought not to be taken as tests. The same remarks apply to the remaining groups of elements studied by Ciamician, and we therefore only give his conclusions.

1. The spectra of oxygen, sulphur, selenium, and tellurium are homologous. Corresponding groups are displaced towards the violet with increasing atomic weight. (This last statement seems disproved by Ciamician's own drawing in the case of tellurium, for out of 13 groups of lines, the 10 last ones are displaced towards the red.)

2. The spectra of phosphorus, arsenic, and antimony are homologous.

3. The more refrangible parts of the spectra of the nitrogen group are homologous to the more refrangible parts both of the oxygen and of the chlorine group.

4. The less refrangible parts of the spectra of the oxygen group are homologous to the less refrangible parts of the spectrum of the calcium group.

The conclusion which Ciamician draws from these facts as to the constitution of the various elements and the probability of their ultimate decomposition lie, fortunately, outside the range of the present report.

We add to the various facts already mentioned the great similarity of the spectra of zinc and cadmium, which has often struck spectroscopists.

Professors Liveing and Dewar[1] have drawn attention to certain relations of wave-lengths which recur in the spectra of lithium, magnesium, and of some lines which are often observed in the spectrum of the chromosphere; they draw from this fact the probable conclusion that these chromospheric lines all belong to the same substance. We mention this fact, as it is one of the first attempts to use the similarity of spectra as a foundation for further conclusions; but we doubt whether many of those conversant with solar matters will agree with Professors Liveing and Dewar. The way in which these different lines appear on different occasions seems to suggest very strongly, if not to prove absolutely, that the celebrated green line of the corona belongs to a different element to that which gives rise to the other chromospheric lines. There is even a different behaviour apparent between the yellow and blue line referred

blance whatever to the spectrum which Messrs. Dewar and Liveing call the spectrum of hydrocarbons; and the spectrum which Messrs. Dewar and Liveing call the hydrogen-magnesium spectrum is the spectrum which Ciamician calls the band-spectrum of magnesium; so that when Ciamician writes that the spectrum of hydrogen-magnesium resembles the spectrum of hydrocarbon, he really makes an altogether different and independent statement when Messrs. Liveing and Dewar make the same remark. But Ciamician quite agrees as to the resemblance pointed out by Messrs. Liveing and Dewar, only he expresses the fact by saying that the spectra of the first order of magnesium and carbon resemble each other.

[1] *Proc. Roy. Soc.* xxviii. p. 475 (1879).

to by Professors Liveing and Dewar, but this may only be due to a difference in temperature.

No systematic attempt has hitherto been made to connect together the different spectra of the same element; relations which seem to hold in one case seem again disproved in others, and no object therefore seems to be gained by entering more closely into this matter at present.

Report of the Committee, consisting of Professors ODLING, HUNTINGTON, *and* HARTLEY, *appointed to investigate by means of Photography the Ultra-Violet Spark Spectra emitted by Metallic Elements, and their combinations under varying conditions. Drawn up by* Professor W. N. HARTLEY (*Secretary*).

THE chief objects to be gained from a knowledge of the character of the Spark Spectra of Metallic Elements, and of the combinations of the elements, are:—

(1) A means of readily identifying the metals by photographs of their line spectra.

(2) A knowledge of the alterations producible in the spectra of metallic salts by the presence of various non-metallic elements.

(3) A knowledge of the alterations in spectra caused by the dilution of metallic solutions.

(4) A possible means of performing rapid quantitative determinations of metallic substances by the aid of photography, and obtaining permanent records of the results.

All these objects have been more or less completely attained, but on account of the extensive inquiry which has been opened up, it is proposed on this occasion to present only a preliminary report.

(1) In order to simplify spectroscopic work, the time of exposure required to produce the most characteristic spectra under various conditions, such as intensity of spark and conductivity, &c., of the electrodes has been carefully ascertained.

(2) A long series of experiments has been made with the object of comparing the spectra of various compounds in solution with those of the elements they contain. In the process of photographing the spectra of solutions it is desirable to eliminate all foreign lines as far as possible, hence the selection of suitable electrodes was a matter of the first consideration. Electrodes of gold, platinum, iridium, and other metals were used, and those of gold proved decidedly the best, as containing the fewest lines, and the metal being a most excellent conductor of electricity.

All these metals are, however, useless compared with electrodes of graphite. The spectrum of graphite consists of eleven or twelve insignificant lines due to the carbon, and about sixty-six lines and bands due to air.

(3) In comparing the spectra of solutions of salts with those of metallic electrodes, it was found that in almost all cases the lines of metals were exactly reproduced from the solution, the *graphic character* being retained except in regard to their continuity. Discontinuous but long

lines, or in certain cases even short lines, appear as long lines in the spectra taken from solutions.

The graphic characteristics of the lines seen in various metallic spectra may thus be classified as—

1. *Continuous lines.* They extend the whole length of the spark, and are accurate representations of the spectroscope slit.

2. *Discontinuous lines.* Those whose length is not so great as the distance between the electrodes.

3. *Extended lines.* Sharp lines which extend above and below the edge of the spectrum, or, in other words, above and below the points of the electrodes.

4. *Blotted lines,* or lines surrounded by a *nimbus.*

5. *Nebulous lines,* or those which are destitute of the sharp clear-cut appearance of most metallic lines.[1]

(4) Insoluble compounds give no spectra when mixed with water or glycerine and exposed to the spark. The non-metallic constituents of salts do not yield any marked series of lines, and therefore do not obscure the metallic spectra.

(5) Experiments have been made to determine the extent of dilution which serves to modify in various ways the spectra of solutions of metallic salts, and that which finally causes the extinction of the most persistent line or lines. The sensitiveness of the reaction varies with different elements and with the period of exposure, the intensity of the spark, and other conditions; I have no difficulty whatever, when working in the manner here indicated, in recognising spectra yielded by solutions which contain no more than $\frac{1}{1000}$th of a *per cent.* of calcium, silver, copper, and $\frac{1}{10000}$th of a *per cent.* of manganese.

Report of the Committee, consisting of Professor ROSCOE, Mr. LOCKYER, Professor DEWAR, Professor LIVEING, Professor SCHUSTER, Captain ABNEY, *and* Dr. W. MARSHALL WATTS (*Secretary*), *appointed to prepare a new series of Tables of Wave Lengths of the Spectra of the Elements.*

THE Committee has but little to report at present. An instrument for the more exact performance of the process of graphical interpolation has been constructed for the Committee, by Messrs. Cooke & Sons, of York, at a cost of 20*l.* This instrument has, however, only been in the hands of the Committee for a few weeks.

The Committee hopes to be in a position to make a fuller report at the next meeting of the Association, and it desires to be reappointed. No further grant of money is at present needed.

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[1] See *Scientific Transactions of the Royal Dublin Society*, vol. i. ser. 2, p. 232.

Report of the Committee, consisting of Professor BALFOUR STEWART, Professor RÜCKER (*Secretary*), *and* Professor T. E. THORPE, *appointed for the purpose of reporting on the Methods employed in the Calibration of Mercurial Thermometers.*

[PLATES I., II., III.]

INTRODUCTION.

IN drawing up the following Report the Committee have desired to present it in the form in which it will be most generally useful. It is therefore divided into two parts. The first contains a brief description of the principal methods of calibration and correction which have been hitherto proposed, an account of the thermometers on which these methods have been tested by the Committee and of the apparatus employed, and a summary of the results arrived at. This portion therefore contains the facts necessary to enable a selection from the various methods to be made by persons intending to undertake the calibration or correction of a thermometer. The second part consists of a fully worked out example of each of the methods, together with remarks of a detailed character. This part will it is hoped be useful in facilitating the calculations required, especially as references to the subject of calibration in English scientific works are rare and meagre.

PART I.

General Review of Methods of Calibration and Correction.

(1) The corrections for the inequalities in the bore of a thermometer tube may be applied in two different ways, distinguished as methods of *calibration* and *correction* respectively.

In the first the length of a column of mercury is measured in various parts of the tube before the scale is etched on it, and the lengths of the divisions are then so adjusted as to make equal differences of scale-readings correspond to equal volumes. In the second the tube is in the first instance furnished with a uniform scale, and a table of corrections is afterwards drawn up, by means of which the same end is attained as before. It will be shown hereafter that a high degree of excellence can be attained by the former method, but although generally used, the scales, even on good thermometers by well-known makers, are not, as a rule, sufficiently correct for very accurate work. They therefore require correction, and the process is rendered very laborious by the varying lengths of the divisions which have to be measured and allowed for in the calculations. The results, too, are probably less accurate than they otherwise would be on account of the irregular forms of the correction curves produced by the superposition of the errors of the tube and scale. A uniform scale, the divisions of which are about a millimetre apart, seems therefore in general the most convenient. Such tubes only should be used as preliminary tests have shown to be of fairly uniform bore.

(2) As all the methods of calibration and correction to be described

depend upon the measurement of the length of columns of mercury in various parts of the tube, it is important to decide upon the best method of separating these 'threads' (as they will hereafter be called) from the main mass of mercury in the tube and bulb.

In general it is in the first place necessary to make the mercury run from the bulb into the tube, so that a column of any length can be obtained when the thermometer is at the ordinary temperature. To effect this the instrument should be held in a vertical position with the bulb uppermost, and the other extremity of the tube should be cautiously tapped against the table. If the mercury does not start it is well, as a preliminary, to heat and cool the bulb several times. Tolerably rapid changes of temperature of a few degrees will often suffice.

The transference of the mercury from the bulb to the tube causes a vacuum bubble to appear in the former, and many writers, among whom A. von Oettingen, in a work often hereafter to be cited ('Ueber die Correction der Thermometer insbesondere über Bessel's Kalibrir-Methode,' Dorpat, 1865, p. 46) may be mentioned, recommend the separation of a column of the desired length by the proper manipulation of this bubble and a system of dexterous jerks. In a wide bore, if the bubble is brought to the junction of the tube and bulb, it is possible by a jerk to effect a disruption between the mercury contained in the one and the other respectively. It is, however, exceedingly difficult, if not impossible, to apply this method satisfactorily to thermometers with narrow bores, and the violent jerks which are required are extremely dangerous to the instruments.

In all the experiments undertaken by the Committee, therefore, the separation of the thread was effected by heat. The use of a blowpipe flame for this purpose has been recommended (Wüllner, 'Lehrbuch der Physik,' vol. iii. p. 14), but such a course is unnecessarily violent and risky. Instead of this, a very small flame, four or five millimetres in height, was used, obtained from the gas issuing from a narrow orifice at the extremity of a piece of glass tubing drawn out fine. Into this the thermometer was introduced, care being taken to heat the tube equally all round, and the rupture was effected at the point where the heat was applied. It is easy thus to break off threads to within a millimetre of the length aimed at. When great accuracy is important it is advisable first to break off a thread longer than that required, and then to separate from it a portion of the desired length. Greater steadiness of the mercurial column while the thermometer is being heated is thus attained. Many dozens of threads have been broken off in this way within the experience of members of the Committee without a single breakage of the instruments employed.

(3) Before proceeding further it will be convenient to define certain terms which will be frequently used.

The *upper* and *lower ends of a thread* are those furthest from and nearest to the bulb respectively.

The point at which the lower end of a thread is placed when a measurement of its length is made, is called the *initial point*.

When by any method the corrections are determined only for a number of selected (and in general approximately equidistant) points, the points so chosen are termed *principal points*. If, when the tube has by means of a system of principal points been divided into a number of parts the relative volumes of which are known, these parts are further subdivided

by any method in which the corrections of the principal points are taken as accurate, the points of subdivision are termed *secondary points.*

The corrections for points intermediate to the principal or secondary points may be determined either by interpolation formulæ or, as is far more convenient, by a graphic method. In the latter case the abscissæ are the uncorrected scale divisions, the ordinates are the corrections to be applied to them, and the curves passing through the points thus determined are called *correction curves.* The curves employed in this investigation have been drawn on paper divided into millimetre squares. In the line of abscissæ two centimetres corresponded to one degree, while an ordinate of one centimetre represented a correction of 0°·01. In the case of second approximations it was often necessary still further to magnify the corrections and to represent 0°·01 by five centimetres. Time and trouble are saved by using an open scale. In the plates the curves are half the size actually used.

If a thermometer has been corrected by several methods, it is necessary in order to compare the results to transform the correction curves, so that the corrections may be the same at two arbitrarily selected points. These, which are in general at the extremities of the scale, are called the *standard points*, and a curve such that the corrections at these points are zero is called a *standard correction curve.*

(4) The transformation of a correction curve is exactly similar to the conversion of a temperature from the Fahrenheit to the Centigrade scale. On the corrected scale equal differences of scale readings correspond to equal tube volumes. This condition will still be fulfilled—(1) if all the corrected readings are increased or diminished by a given amount; (2) if the difference between any two readings is increased or diminished in a given ratio.

Let x be any point on the scale $\phi(x)$ its correction. To make the correction for the lower standard point I zero, we have to diminish all the readings by ϕ (I). Hence the reading for x becomes $x+\phi(x)-\phi$ (I).

Let U and ϕ(U) be the upper standard point and its correction, and let

$$\mathrm{U} + \phi(\mathrm{U}) - (\mathrm{I} + \phi(\mathrm{I})) = \mathrm{N} + a,$$

where

$$\mathrm{U} - \mathrm{I} = \mathrm{N}.$$

Hence after the scale divisions are altered in the ratio necessary to reduce the correction for the upper standard point to zero, the reading for x becomes

$$\left\{ x + \phi(x) - \phi(\mathrm{I}) \right\} \frac{\mathrm{N}}{\mathrm{N} + a}.$$

For facility of calculation this is thrown into the more convenient form—

$$x + \phi(x) - \phi(\mathrm{I}) - \frac{a}{\mathrm{N} + a}\left\{ x + \phi(x) - \phi(\mathrm{I}) \right\}$$

$$= x + \phi(x) - \phi(\mathrm{I}) - \frac{a}{\mathrm{N}}\left(1 - \frac{a}{\mathrm{N}}\right)\left\{ x + \phi(x) - \phi(\mathrm{I}) \right\}$$

approximately,

$$= x + \phi(x) - \phi(\mathrm{I}) - \frac{a}{\mathrm{N}}\left\{ x + \phi(x) - \phi(\mathrm{I}) - \frac{a}{\mathrm{N}}x \right\}$$

approximately, whence the transformation can, as shown hereafter, be easily effected.

(5) Methods of calibration and correction may be divided into four classes.

The first contains what may be called the *step by step* method, which is due to Gay-Lussac.[1] In it a thread of mercury is measured in a position A B, then shifted to B C, so that the lower end is in the position previously occupied by the upper end, then measured again, and so on for the whole length of the tube. From these measures the corrections for the points B, C, D, &c. can be deduced.

The second class contains what may be called *principal point* methods. In these a number of equidistant points are selected on the uncorrected scale, and the corrections for these are determined by means of threads the lengths of which are approximately equal to or multiples of the distance between two consecutive points.

Several methods are included in this class.

Hällström's[2] is a modification of Gay-Lussac's, in which an attempt is made to prevent the risk of the accumulation of errors inherent in the use of very short threads. Two slightly different varieties of Hällström's method are described by A. von Oettingen and Pfaundler, of which the latter has been employed by the Committee. If the tube be divided into the parts A B, B C, &c. by principal points, a thread approximately equal to two of these parts is measured with its lower end at each of the points in turn. A second thread nearly equal to three of the parts is measured with its lower end at each of the two lowest principal points, and from these observations the corrections are deduced as described in Part II.

Dr. A. Handl[3] has recently described a method of calibration which appears to differ from those of Gay-Lussac and Hällström only in the form of the calculations.

Another method has been devised by M. Thiesen.[4] The scale being divided into n parts by principal points, threads equal in length to $1, 2, \ldots n-1$ of these intervals are measured with their lower ends coincident in turn with as many of the principal points as possible, and hence the corrections are deduced.

Märek[5] has applied the method of least squares to the calculation of the corrections for any number of principal points less than seven.

By all these methods the corrections can be determined for as many points as may be desired, either by taking the principal points near together, or by breaking up the intervals between them by secondary points. There is, however, one method—Rudberg's[6]—the essential feature of which is the breaking up of corrected scale intervals into smaller sections. This method therefore constitutes the third class, which may be called that of *repeated subdivision*. In this method the tube is first divided into two equal parts by measuring a thread of approximately half its volume, when the lower and upper ends are in turn at the extremities of the tube. These portions are then subdivided into three

[1] See Pierre, *Pogg. Annalen*, Bd. 57, S. 554, and *Ann. de Chim. et de Phys.* sér. iii. iv. p. 427; Welsh, *Proc. Roy. Soc.* vi. p. 178, and *Phil. Mag.* (4) iv. p. 306; A. von Oettingen, *op. cit.* p. 43, Verdet, *Cours de Physique*, i. p. 64.

[2] See *Pogg. Ann.* Bd. 9, S. 535; Müller-Pouillet's *Lehrbuch der Physik* (Pfaundler); A. von Oettingen, *op. cit.* S. 51.

[3] *Carl's Repertorium*, Bd. xvii. Ht. 5.

[4] *Ibid.* Bd. xv. S. 285.

[5] *Ibid.* Bd. xv. S. 300.

[6] *Pogg. Annalen*, Bd. 40, S. 574; A. von Oettingen, *op. cit.* S. 50.

by means of a thread of about one-third the whole length of the tube, which is measured in the positions (see figure, p. 178) A *d*, *d e*, *e* B, C *f*, and C *g*. The process can then be carried further, as described in the detailed account of this method.

The fourth class of correction methods also comprises one only—viz., Bessel's—which may be called a *distributed point* method.

In this all the threads are measured with their lower ends at certain selected points, but as their lengths are not multiples of the distances between these points, but are within wide limits arbitrary, the corrections are determined at numerous points more or less irregularly distributed over the scale.

In von Oettingen's modification of the method the corrections are finally calculated by drawing correction curves through the points determined by each thread, and taking the means of their ordinates. Professors Thorpe and Rücker have introduced some changes into von Oettingen's method of correcting the lower and upper parts of the scale. An example of both systems, and a full discussion of the method are given in Part II. Although too detailed to be introduced here it may be said that the examples given prove that Professors Thorpe and Rücker's alterations increase the rapidity with which the method approximates to the true correction curve.

All the methods above mentioned (with the exception of Handl's) have been tested by the Committee, and as the results are probably sufficient for the practical purpose in view, they have not extended their investigation to several others which have been proposed by various writers.

They may, however, refer to the plans suggested by Egen ('Pogg. Ann.' Bd. XI. s. 529), Rowland ('Proceedings of the American Academy of Arts and Sciences,' June 1879), and Pickering ('Physical Manipulation,' Part II., p. 75).

(6) Many of the methods of correction theoretically require that one or both ends of the thread should occupy definite positions in the scale. It is impossible, unless the tube is uniform or is perfectly corrected, to establish this coincidence at both ends, inasmuch as a thread which would comply with the condition in one part of the scale would fail to fulfil it in others. In the case, too, where the theoretical position of one end of a thread is indicated by a scale mark, the breadth of this is often so considerable that it is difficult to observe with accuracy the position of the end of a thread which is concealed by it.

Sometimes it is impossible, and often it is inconvenient, to bring the thread end into its theoretical position. In cases where errors might be introduced by this failure to comply with the exact conditions of the method, they may be allowed for in two slightly different ways.

The first plan is that of further approximation. The corrections for the extremities taken out from the correction curve are applied to the measured thread lengths, and then, by repeating the calculations with the corrected values, further corrections are obtained, which must be added to those previously found. A second approximation is thus worked out in Part II. in the second example of Gay-Lussac's method (p. 166).

In some cases, however, if the threads are not measured in their theoretical positions, it is convenient to avoid the necessity for a second approximation by the preliminary use of a correction curve drawn by any simple method. Let the thread end be situated at M, and let the cor-

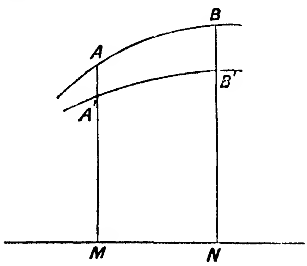
rection be required for a neighbouring point, N. Let A′ B′ be an approximate, and A B the true correction curve. (See figure below).

Let $A'M = \phi_1(M)$ $AM = \phi_2(M)$, and so on.
Then, if $AA' = \alpha$, $BB' = \beta$, it is evident that

$$\phi_2(M) - \phi_2(N) = \phi_1(M) - \phi_1(N) + \alpha - \beta.$$

Now, in the method of approximation, the assumption made in the first approximation is that the right-hand side of this equation is zero, or that $\phi_2(M) = \phi_2(N)$.

A nearer approach to the truth is reached by neglecting $\alpha - \beta$ only, and obtaining the values of $\phi_1(M)$ and $\phi_1(N)$ from an approximate curve. Since the two curves in general differ but little, and M and N are always very near together, the error thus introduced is obviously in general less than that caused by neglecting $\phi_1(M) - \phi_1(N)$. In other words, since the curves are nearly parallel, the difference between A A′ and B B′ is in general much less than that between M A′ and N B′, or M A and N B.



Theoretically, of course, the error due to the neglect of $\alpha - \beta$ would be greatest when the two curves sloped in opposite directions in the neighbourhood of M N. The only case, however, where a doubt as to the direction of slope could arise would be near to a maximum or minimum, when the whole error would be so small as to be negligible.

This method, which is employed by Märek (*loc. cit.*), is illustrated in the case of Rudberg's and other methods in Part II. Since by it the corrections at points are determined from measurements made on threads whose ends lie near to but not actually at them, the corrections may be regarded as transferred by means of the preliminary curve from the observed to the theoretical points, and it is convenient to refer to it as the *method of transference.*

If the theoretical points are u and i, if the extremities of the thread lie at $u + \Delta u$ and $i + \Delta i$, and if $\phi(u)$ represents the correction at u, and so on, the true thread length is

$$u + \Delta u + \phi\,(u + \Delta u) - \{i + \Delta i + \phi\,(i + \Delta i)\}.$$

Here $u + \Delta u - (i + \Delta i) = t$ say, is the uncorrected thread length, and thus the true thread length

$$= \Big\{ t + \{\phi\,(u + \Delta u) - \phi\,(u)\} - \{\phi\,(i + \Delta i) - \phi\,(i)\} \Big\} + \phi\,(u) - \phi\,(i).$$

The corrections within the large brackets being determined from the approximate curve, the expression contained in it is in this method used instead of t, and is referred to as the *transferred thread length.*

(7) In estimating the value of any method, three points require consideration—viz. the accuracy attainable, the time and labour required, and the cost of the necessary apparatus. The more accurate the apparatus used, the simpler may be the method of calculation employed. Thus, the chief objection to the step-by-step and subdivision methods is that the errors are cumulative, and that by an unfortunate combination of successive errors of the same sign, considerable inaccuracy may be introduced. It is, however, evident that this objection would vanish if

the apparatus used for measuring the threads were sufficiently sensitive to make the accumulated errors of thread-measurement insensible when compared with the error of reading introduced when the thermometer is used.

The Committee have been able to study the results produced by different instruments, as well as by different methods, as will appear from the following *résumé* of the observations considered in the preparation of this Report.

Some time ago Professors Thorpe and Rücker obtained a number of mercurial thermometers for the purpose of comparison with the air thermometer. A full description of these instruments is given in Table I. :—

TABLE I.

Thermometer	Owner	Maker	Extent of scale in degrees C.	Average length of degree in m.m.
A	Dr. Thorpe	Casella	−9 to 50	9·3
B	"	"	48 " 110	8·9
C	"	"	98 " 142	11·2
R_1	Prof. Rücker	"	−11 " 31	12·3
R_2	"	"	21 " 67	11·1
R_3	"	"	55 " 107	10·2
561	Kew Committee	Kew Observatory	−11·5 " 29	12·9
562	"	"	19·5 " 68	11·2
563	"	"	51 " 107	9·5
O_1	Owens College	Owens College Laboratory	−11 " 30	11·5
O_2	"	"	21 " 69	9·8
O_3	"	"	55 " 107	9·3

Those numbered 561–2–3 were constructed and calibrated in the Kew Observatory, and those indicated by the symbols O_1, O_2, O_3, in the Physical Laboratory of the Owens College. In the case of the Kew instruments, the method of calculation adopted was that introduced into the Observatory by the late Mr. Welsh, and explained by him in the 'Report of the British Association' for 1853, p. 35, which, as it is practically the same as that of Gay-Lussac, need not be further described.

The Owens College instruments were furnished with a uniform scale.

In addition to the construction of the thermometers, the authorities of the Observatory and the Owens College undertook to perform, in accordance with the directions of Professors Thorpe and Rücker, the measurements necessary for their correction by Bessel's method. The apparatus used in each case was an excellent dividing engine. The accuracy of the measurements and of the correction curves obtained is evident from the fact that the difference between any one measurement of the length of a mercurial thread expressed in terms of the corrected scale, and the mean length of that thread, equals or exceeds 0°·01 C. (i.e. about 0·1 m.m.), in eleven only out of a total of 880 observations made in all on the six instruments.

(8) The application of Bessel's method, therefore, to the Kew instruments, afforded an excellent test of Welsh's method by which they had been calibrated. The result was reported to Section A of the British Association at York (Report 1881, p. 541), in a paper from which the following is an extract:—

'The original calibration was so accurate that the second approximation of Bessel's method was unnecessary in two cases, and was only partially carried out in the third.

'The maximum positive and negative corrections were in the case of

Th. 561 + 0°·004 C. and − 0°·004 C.
,, 562 + 0°·002 C. and − 0°·005 C.
,, 563 + 0°·008 C. and − 0°·011 C.

'As will be seen from the above description of the thermometers, the larger of these quantities are about equal to the limit of certainty in reading.

'In no case would the calibration error in the determination of a difference of temperature have amounted to 0°·02 C.'

(9) The remainder of the thermometers, viz. A, B, C, and R_1, R_2, R_3, had been calibrated by the maker, and were corrected by Bessel's method in the Physical Laboratory of the Yorkshire College.

The instrument used was copied from one devised by and kindly lent for the purpose by Mr. F. Brown, which he has lately described to the Physical Society.[1] It consists of a wooden base to which the thermometer is attached parallel to a slot in which a small brass plate slides, carrying with it a vertical microscope furnished with a spider line. The microscope is moved by rackwork on the brass plate parallel to the thermometer, and the distance travelled is determined by a millimetre scale. Readings can be made by a vernier to 0·1 m.m., and with the help of a lens estimations can be made correct to 0·02 or 0·03 m.m. In the form described by Mr. Brown a split object-glass is used to bring the mercury in the bore and the scale divisions into focus together. In that employed in this investigation this was omitted, and the microscope was moved vertically by rackwork to bring the mercury and scale into view in turn. This worked well. Any error due to want of verticality produced in the measurement at one end of the thread would be compensated at the other, if only the direction of the tube remained the same. That it did so is proved by the fact that two measures of the same thread length rarely differed by more than 0·03 m.m., which was well within the limits of the sum of the estimation errors possible at both ends.

This instrument was employed because it was believed that, with proper precautions, and with so accurate a method of calibration as Bessel's, it would serve to correct the thermometers to the required degree of accuracy. This anticipation has been fulfilled, and as the instrument is extremely convenient and relatively inexpensive, it may be well to state precisely the conditions under which it was used. Inasmuch as the thread lengths were required in terms of scale divisions, the instrument was never used to measure the entire length of a thread, but only the amount by which it was distant from a neighbouring scale division.

(10) The position of the end of the thread was always determined by measuring the distance from the nearest division which was clear of the thread. Thus, if a and b be the extremities of the thread, and AA′, BB′

the nearest scale divisions, the distances A a and B b were measured, even if they were much greater than A′ a and B′ b.

[1] *Phil. Mag.* [5] vol. xiv. p. 59.

In what follows, the *nearest* division therefore means the nearest division beyond and clear of the thread.

The word *reading* means reading on the scale of the calibrating instrument, and in terms of millimetres.

In a particular thermometer graduated from 55° to 107° C., the mean length of a degree between 55° and 75° was found to be 10·50 m.m.

Hence, to convert readings between 55° and 75° into degrees, we have to multiply by $\frac{1}{10\cdot 50} = \cdot 095$.

The corresponding factors for the whole scale were as follows:—

Between 55° and 75°	the factor	= ·095.
,, 75° and 85°	,, ,,	= ·097.
,, 85° and 90°	,, ,,	= ·100.
,, 90° and 107°	,, ,,	= ·104.

The initial points chosen were 55°, 58°, and 61°, &c. The method of exhibiting the results of the measurement is shown in the accompanying Table II. which is made more cumbrous than in actual practice by a full explanation of the meaning of the figures in each column.

The results of two sets of measures only are given.

The scales of the thermometers were carefully tested in various parts, and it was generally found that a group of consecutive divisions, all of which were equal in magnitude, was bounded at either end by other groups, in which the length of a division differed more or less considerably from that of those included in it.

This was no doubt due to the fact that the scales were already adjusted by the maker to the varying dimensions of the bores, though not with the necessary accuracy. It was therefore possible to divide the scale into parts, throughout each of which the same factor could be used for converting the readings of the calibrating instrument (given in millimetres) into degrees. An example of such a division is given above.

It may here be stated once for all that in the case of all the thread lengths required for the observations detailed in Part II. the corrections for the varying lengths of the scale divisions were thus made. The temperature, too, was frequently observed by means of a thermometer placed close to that operated on, and the thread lengths were corrected by subtracting 0·00016 of their length for every degree Centigrade above the standard temperature for the set of observations in which they were made.

The apparent mean error, taken without regard to sign of the thread lengths measured by this instrument is about double that of the more accurate instruments employed at Kew and the Owens College. In the case of Thermometer C, which was carefully calibrated by Bessel's method for the purposes of this Report, it amounts to 0°·0024, or about 0·033 m.m. As each thread was measured only once, and required four readings of the vernier, this result is satisfactory. The error in the estimation figures obtained by the vernier is indeed much greater than the error of setting the cross-wire to the point to be measured. Additional accuracy could, of course, readily be obtained by fitting the eye-piece with a micrometer screw to read over 2 or 3 m.m. only. Inasmuch also as in the method of measurement described the sum of the two small quantities Aa, Bb (see p. 152), is alone required, it would be convenient, if a uniform scale were used, to transfer the microscope from a to b by a screw or rackwork, without altering the position of the

Table II.

Temperature at time of observation	Lower end of thread			Upper end			VII.	VIII.	IX.	X.	XI.	XII.	XIII.
	I. Reading for lower end of thread	II. Nearest scale division	III. Reading for nearest scale division	IV. Reading for upper end of thread	V. Nearest scale division	VI. Reading for nearest scale division	Distance of lower end from nearest scale division = cols. I.–III.	Distance of upper do. = cols. VI.–IV.	Col. VII. in terms of degrees	Col. VIII. in terms of degrees	Sum of distances of ends of thread from nearest scale division = cols. IX. + X.	Distance between nearest scale divisions = cols. V.–II	Length of thread — cols. XII.–XI.
15°·0	29·37	55	29·01	28·88	79·7	28·95	·36	·07	·0342[1]	·0068[2]	·0410	24·7	24·659
&c.	„	„	„	„	„	„	„	„	„	„	„	„	„
14°·9	27·72	64	27·02	26·83	88·9	27·57	·70	·74	·0665[3]	·0740[4]	·1405	24·9	24·760

1. Factor used = ... ·095
2. „ „ = ... ·097
3. Factor used = ... ·095
4. „ „ = ... ·100

vernier. The errors of reading would thus be reduced from four to two, and the maximum possible inaccuracy halved.

(11) In order to compare experimentally the different methods of correction, the Committee have applied them to the same thermometer. The instrument selected was thermometer C, and the methods applied to it were those of Gay-Lussac, Hällström, Rudberg, Thiesen, Märek, and Bessel—the latter both as modified by von Oettingen, and also with the additional changes introduced by Professors Thorpe and Rücker. The measurements were made in the Physical Laboratory of the Yorkshire College.

Those for Bessel's method, and for the first example of Gay-Lussac's method, were performed by Professor Rücker. The remainder, together with much of the laborious calculation required, were kindly undertaken by Mr. W. Heatón, M.A., Demonstrator in the Clarendon Laboratory of the University of Oxford, to whom the warm thanks of the Committee are due for the labour and skill which he has expended on the investigation. It is owing to his help that they are able to present the Report without further delay.

In the first place the thermometer was corrected by Gay-Lussac's method. The thread used was about 19 m.m. (1°·6) long. When it was moved the lower end was always brought very near to, though not into absolute coincidence with, the position previously occupied by the upper. An inspection of the curve when completed showed that the errors introduced by these small deviations from the theoretical position were absolutely negligible. The length of the thread, together with that of the scale divisions in which its extremities lay, was measured twice for each position of the thread. As when the thread was displaced, the lower end lay in the same division as that which previously contained the upper, each division was really measured four times, and the mean of these values, which rarely differed by more than 0°·003, was taken as the true value.

The standard correction curve obtained is exhibited in fig. 1, Plate I.

All the calculations, together with those required in the other calibrations to be described, are given in Part II.

In the second application of Gay-Lussac's method to the thermometer the thread employed was somewhat longer, viz. about 22 m.m. (2°). Instead of measuring each division in which the ends lay, the scale of the thermometer was previously studied, and was found, as is usual in thermometers calibrated by the maker, to consist of groups of divisions of equal length. The values of these were determined and used as above described. Another difference in the application of the method was that it was now used as a principal point method to determine the correction at every second degree. As, however, the length of the thread was very nearly 2°, the divergence from the theory of the step-by-step method was small, though considerably larger than in the last case.

To eliminate any error a preliminary curve was drawn, and the method of approximation applied. The distance between the positions of the upper and lower ends (assumed in the first approximation coincident) was never greater than 2·2 m.m. (0°·2), and the maximum correction introduced in the second approximation was 0°·007.

In what follows the correction curve obtained by the use of the thread 2° long was used as a first approximation curve to apply the transference

of corrections above described to the various methods investigated. It is shown in fig. 1, Plate I.

Gay-Lussac's method was also applied a third time to the thermometer. On this occasion a much longer thread 44 m.m. (4°) in length was used. The method of transference was used in finding the corrections, and the observations with the thread 2° long were used (for the sake of example) to obtain some secondary points between those found by the longer thread.

The points determined are shown in fig. 1, Plate I.

Hällström's and Thiesen's methods were applied to find the corrections of ten principal points, Märek's of five, Rudberg's of twelve. In all these the method of transference was applied. Bessel's method was also applied, the principal points being 2° apart. The calculations were performed twice, as above stated.

(12) The following Table contains a statement of the number of thread lengths measured in the application of each of these methods.

TABLE III.

Method	Number of measures required		Total	Number of points determined by method alone	Number of points determined by method and preliminary curve
	(1) By method alone	(2) By preliminary curves used in transference			
Gay-Lussac I.	26		26	26	26
" " II.	20		20	20	20
" " III.	10	20	30	10	20
Hällström	11	20	31	10	20
Thiesen	54	20	74	10	20
Märek	14	20	34	5	20
Rudberg	15	20	35	12	31
Bessel	138		138	148	8

The difference in the amount of labour required by the different methods is not to be measured by the number of observations alone.

In the case of the methods of Gay-Lussac and Thiesen the calculations are extremely short and easy; those of Hällström and Rudberg are not lengthy, but they lack the symmetry of the two just named, and are therefore less simple in application. The longest of these methods, that of Thiesen, may be completed in a few hours, but the calculations and curves which Bessel's method requires demand an amount of time which must be measured by days rather than hours. The operation of reducing the thread lengths to scale divisions, and performing the work for two full approximations, requires about four days' constant attention.

It is on the other hand true that the same extreme accuracy of measurement is not necessary, and thus in the example given each thread was measured once only, instead of twice as in the case of the other methods. This is justified partly by the result which previous experience had shown to be probable, viz. that the errors made under such circumstances are small. Only one of the 138 measures gives an apparent error as great as 0°·01, and the mean is, as has been stated, 0°·0024. The

other justification of the course adopted is that, as will immediately be shown, an error of measurement in Bessel's method is of relatively little importance.

(13) This question is fully discussed in Part II. The following Table may, however, be given here. If e is the probable error of a single thread measurement, and $m\,e$ the probable error of a correction, the numbers in the Table are the values of m^2, when ten principal points have been found, and are therefore proportional to the squares of the probable errors, or to the reciprocals of the combination weights of the corrections of the scale obtained by the method to which they refer.

The probable errors of all thread lengths are taken as the same, though measures on long threads are less reliable than those on short, on account of their greater mobility, and the greater value of the temperature corrections with respect to the error of reading. In the case of Rudberg's and Bessel's methods the numbers can only be considered as approximations.

TABLE IV.

	Gay-Lussac		Rudberg	Hällström	Thiesen	Bessel
	Thread 2°	Thread 4°				
0	0	0	0	0	0	0
1	1·8	0·9	1·4	1·1	0·18	0·10
2	3·2	1·6	1·8	0·8	0·18	0·10
3	4·2	2·1	0·7	1·1	0·18	0·10
4	4·8	2·4	0·6	1·2	0·18	0·09
5	5·0	2·5	0·5	2·5	0·18	0·09
6	4·8	2·4	0·6	1·2	0·18	0·09
7	4·2	2·1	0·7	4·3	0·18	0·10
8	3·2	1·6	1·8	0·8	0·18	0·10
9	1·8	0·9	1·4	6·5	0·18	0·10
10	0	0	0	0	0	0

To make the result of this table more obvious, the numbers have been plotted down and curves drawn through them in the following figure. The curves serve only to connect the points given by the same method. At these points their ordinates are proportional to the squares of the probable errors of the corrections. The enormous differences between them will be at once appreciated. Care, however, must be taken to avoid drawing false conclusions. The numbers have no reference to any approximate assumptions. They refer only to the methods as exemplified in this Report, *e.g.* for Bessel's and Thiesen's methods, with 10 threads and so on. Had Thiesen's method been applied to determine five points only, instead of ten as was actually the case, the ordinates would have been doubled. This points to a fundamental distinction between such a method as Thiesen's and Gay-Lussac's. *Cœteris paribus*, the larger the number of points corrected by the former, the more accurate is the correction of each, whereas in Gay-Lussac's method the reverse statement holds good.

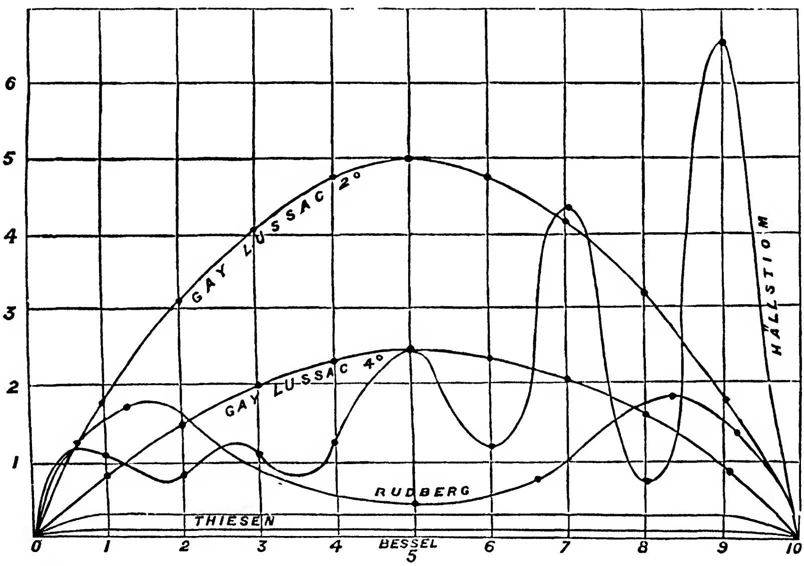
The extreme irregularity of the Hällström curve depends on the want of symmetry of the method. The extraordinary accumulation of the errors at the seventh and ninth points is sufficient to condemn it as presented by Pfaundler.

(14) Perhaps, however, more is to be learnt from the curves actually obtained than from purely theoretical discussion.

Unless the greatest care is exercised, the errors due to 'taste' in drawing the curves may far exceed those produced by mere instrumental inaccuracies.

An excellent example of this is afforded in the neighbourhood of the point 135° on Thermometer C.

Figure 2, Plate I., gives a part of the curve obtained by the Gay-Lussac method with the thread 1°·6 long. The points surrounded by circles are those obtained by the thread 4° long. The dotted line is that actually drawn by a person unacquainted with the form of the other curve. Thus at 138° a difference of 0°·012 is introduced. A similar result was obtained with the two Gay-Lussac curves shown in fig. 1. The dotted curve happened to have a point at 135° where the correction was found to be very low, in this agreeing with the Bessel curve, fig. 3.



The other curve missed this point, and gave a much higher correction at 136°. Probably both are nearly right. There is evidently some sudden change or irregularity at this part of the scale, to fully investigate which a number of points taken very close together would be required.

If a thermometer is required to be accurate to 0·05 m.m. (0°·005) points must be determined at intervals not greater than 20 m.m., and wherever any sudden bend in the curve occurs, a secondary calibration of that part of the scale should be instituted with a shorter thread.

(15) The following Table (V.) gives the corrections for the principal points as determined by all the methods. Rudberg's is omitted, as these points could not be directly corrected by that method. The corrections obtained by it are, however, plotted down in fig. 3, Plate I.

(16) A very careful comparison has been made between the results given by Bessel's and the other methods. The two methods of calculation applied to it are fully discussed in Part II. The result is that whereas at the end of the second approximation the curves disagree by nearly

TABLE V.
In terms of 0°·001.

	Gay-Lussac			Hällström	Thiesen	Marek	Bessel
	I.	II.	III.				
100	0	0	0	0	0	0	0
104	121	120	116	120	121	—	120
108	155	155	151	153	156	156	151
112	106	109	104	107	109	—	104
116	108	116	113	115	117	116	115
120	130	136	135	137	138	—	135
124	106	112	111	109	113	112	109
128	108	111	111	114	112	—	108
132	56	60	61	56	61	62	54
136	2	10	12	13	10	—	4
140	0	0	0	0	0	0	0

0°·01, when the third approximation is partly carried out, that obtained by Professors Thorpe and Rücker's method remains virtually unaltered, while von Oettingen's is brought into agreement with it. The former, therefore, though somewhat the longer, is taken as the more accurate method.

(17) The discrepancies between the Bessel and the second Gay-Lussac curve were next investigated. The extremely small effect produced on the correction at any one point by any one measurement of a thread length in Bessel's method, makes it possible to use these threads as means of comparison. The corrections for the upper and initial points of all the threads measured in Bessel's method were taken out both from the Bessel's curve, fig. 3, Plate I., and the Gay-Lussac curve, Example 2, fig. 1, Plate I. The thread lengths were corrected by these, and then, by subtracting from them the corrected mean thread lengths, the apparent errors of the measures were deduced.

As ten threads were measured at each of the initial points, if the correction for any one of these points was too high or too low, the threads measured at it would be too short or too long.

This fact can be used to test the relative accuracy of the two curves. For instance, at 108°, the mean apparent error of the threads, when corrected by Bessel's curve, was + 0°·001, which would show that the correction of the initial point was too low, and should be changed from 0°·151 to 0°·152. Applying similar reasoning to the other initial points, and to both the Bessel and Gay-Lussac curves, the following Table results:—

TABLE VI.
In terms of 0°·001.

I.	II. Gay-Lussac	III. Bessel	IV. Gay-Lussac	V. Bessel	VI. Gay-Lussac	VII. Bessel
100	0	0	1	0	1	0
102	80	81	1	−1	81	80
104	121	120	−1	−1	120	119
106	149	146	0	0	149	146
108	155	151	−1	1	154	152
110	142	142	1	0	143	142
112	109	104	−2	1	107	105
114	115	113	1	1	116	114
116	116	115	2	0	118	115

Column I. gives the principal points; Columns II. and III. the corrections according to Gay-Lussac's and Bessel's curves; Columns IV. and V. the mean excesses of the thread lengths, according as they are corrected by one or the other curve; Columns VI. and VII., the corrections of the initial points themselves corrected by means of these excesses. It will be observed that the differences are reduced, but as the displacement of each curve by the corrections is about the same, it is difficult to say which is the more accurate between 100° and 110°.

Another point of divergence occurring about 135°, all the threads whose ends fell on this part of the scale were picked out, thirteen in number. Their differences from the means, expressed in thousandths, were, in the case of Bessel's curve,

0, 0, −1, 6, 1, −1, 5, 4, 0, −4, −2, −6, 2; total 4,

and in the case of Gay-Lussac's curve,

4, 3, −1, 5, 1, 2, 1, 8, 2, 0, 1, −3, 8; total 31.

This shows that the lengths given by the Gay-Lussac curve are on the whole too great, or that in this part it lies too high, and is the less accurate. On the whole, then, the Bessel curve seems to be the best, as theory would indicate. The extreme difficulty of obtaining an agreement throughout to less than 0°·005 is, however, shown by the discrepancies between the numbers given by Bessel's and Thiesen's methods. The probable error of a thread measurement is, according to the number given by Bessel's curve, 0°·0025. Hence the probable error of a correction ought, according to Table IV., to be about 0°·0008 and 0°·001, according as it was determined by Bessel's or Thiesen's methods. They differ, however, in several places by 0°·005, and each receives independent confirmation from one of the other methods.

(18) The agreement in Table V. will or will not be considered good according to the standard of accuracy to which the readings of the thermometer, when in actual use, attain.

Two members of the Committee (Professors Thorpe and Rücker) have frequently had occasion to read the same thermometer together, and they always agree to 0°·01 (0·1 m.m.). This indicates a possible reading error of $\pm$ 0°·005 (0·05 m.m.), when no lens or other aid is used. Pernet has, however, come to the conclusion that the distance between the fixed points can be determined to 0°·001, and thus Märek and others think that a thermometer should be calibrated to 0°·002 at least. It may therefore be convenient to lay down three standards of accuracy, defined by the conditions that the differences between the corrected and the true scales shall not exceed 0°·1 m.m. (0°·01 in Thermometer C) in the first, 0°·05 m.m. in the second, and 0°·02 m.m. in the third.

(19) The observations on the Kew thermometers show that the first standard can be reached by a *calibration* conducted after Welsh's method with a good dividing engine. Inasmuch as the two Gay-Lussac curves shown in fig. 1, Plate I., nowhere differ by more than 0°·12 m.m. (0°·011), except at the point 135°, where the difference could no doubt be reduced by a subsidiary correction near that point, the first standard is certainly attainable by a single Gay-Lussac correction conducted with a short thread and with Mr. Brown's instrument, provided that special attention be paid to the accurate investigation of maxima and minima.

The second standard can be obtained with Mr. Brown's instrument

either by Bessel's method or by the mean of two good correction curves obtained by Gay-Lussac's method with short threads. This last statement is proved by reference to fig. 3, Plate I. The mean Gay-Lussac curve and the Bessel's curve are there shown side by side, and it will be observed that at the points where the Bessel's correction differs most from Thiesen's, the mean curve diminishes the difference. As the Bessel and the Thiesen curves do not differ by more than 0·007, nor the Bessel and the mean Gay-Lussac curves by more than 0°·005, the latter may certainly be taken as correct to within this limit.

There seems, too, no doubt that any of the principal point methods will, with Mr. Brown's instrument, and the methods of approximation or transference used as in this Report, give the principal points correct to 0°·005. Among these the preference is certainly due to Thiesen's. It must, however, be remembered that the points corrected by these methods in this paper are too far apart to enable accurate curves to be drawn. They are sufficiently numerous to enable a comparison between the methods to be made, which is all that was desired. If they are used to determine points nearer together the number of measurements required and the labour of calculation rapidly increase.

It seems therefore better to use these methods only as auxiliaries to a short-thread Gay-Lussac curve.

This should be drawn as a first approximation, the length of the thread being a sub-multiple of the distance between the principal points determined by the more elaborate method. The corrections at these points should then be found, applying the method of transference by means of the Gay-Lussac curve, and, finally, the measures made on the short thread should be used to determine secondary between the principal points. The third standard of accuracy is more difficult of attainment. The discrepancies between Bessel's and Thiesen's figures in Table V. prevent certainty that either curve is correct to less than 0°·002. The method of least squares, as applied by Mârek, does not seem to produce numbers differing by more than 0·001 from those given by Thiesen's method. The application of such calculations to so small a number of measures is, indeed, of doubtful utility.

The thread-lengths measured at Kew do not after correction, when treated as above described (p. 159) to discover residual errors in the initial points, anywhere show signs of an error as great as 0°·002. The same statement, however, holds good for Bessel's curve, obtained in this Report with Mr. Brown's instrument, and yet, as has just been shown, it is difficult to feel certain that it is correct to 0°·002. On the whole, therefore, there can be no doubt that this standard of accuracy can be reached only by the most accurate apparatus and most perfect methods.

The second standard in which the error of calibration is less than the error of an unassisted-eye reading of the thermometer is that which will probably be most generally aimed at.

For this purpose the Committee, after considerable experience of Bessel's method on the part of some of its members, are (if an instrument such as Mr. Brown's or a dividing engine is used) decidedly in favour of the use of less laborious processes. The extreme length of the calculations required by Bessel's method is in itself a serious drawback—an undetected error may vitiate many hours' work. The same or a less amount of time spent in obtaining independent correction curves by Gay-

Lussac's method, and taking the mean, would give an equally good result with much less trouble in calculation.

(20) On the whole, then, the Committee think that, if the following rules are obeyed, an accuracy of $0^{\circ}\cdot05$ m.m. in the correction of a thermometer scale can be attained.

I. If a dividing engine is used, select principal points about 40 m.m. apart.[1]

Correct by measures on a thread about $\frac{40}{3}$ m.m. long, employing Gay-Lussac's as a principal point method. If necessary apply a second approximation.

This will probably be sufficiently accurate. It may, however, be well to check by using a thread 40 m.m. long to redetermine the principal points according to Gay-Lussac's method, applying the method of transference by means of the curve obtained with a short thread. Combine the results of the two sets of measures at the principal points, giving to the values obtained by the two threads weights proportional to their lengths.

Use the shorter thread to determine secondary points. Examine further any maxima or minima in the neighbourhood of which the curves slope steeply.

The total number of measures which would be required to apply this method to Thermometer C would be ten on the long and thirty on the short thread.

II. If an instrument such as Mr. Brown's is used, reading to 0·1 m.m. on the vernier and to less by estimation.

Select principal points about 40 m.m. apart.

Apply Gay-Lussac's method twice by measurement on threads 20 and $\frac{40}{3}$ m.m. long respectively. Use the method as a principal point method, and make the points originally selected principal points for both correction curves.

If necessary, apply a second approximation in each case.

If the two curves obtained agree to within 0·1 m.m. their mean will probably be as accurate as is desired. In taking the mean the weight assigned to each should be proportional to the thread-length. If, however, greater certainty is desired, it may be well to determine the principal points, either by Gay-Lussac's method, using a thread 40 m.m. long, or by Thiesen's.

In the former case combine the three curves at the principal points, giving the weights 6, 3, and 2 to the corrections obtained by the longest, intermediate, and shortest threads respectively.

If Thiesen's method is employed and there are n principal points, the weights assigned to the three corrections of the r^{th} principal point will be

$$3\,nr\,(n-r),\ 3\,(n-1),\ \text{and}\ 2\,(n-1)$$

to that given by Thiesen's method and those obtained by Gay-Lussac's with the longer and shorter thread respectively. This gives so great a preponderance to Thiesen's method that unless the discrepancies are very great the corrections at the principal points practically depend upon it alone.

[1] The numbers given in these rules refer to a thermometer about 400 m.m. long, on which ten principal points are to be found. They can readily be modified so as to apply to instruments of other dimensions.

If these rules are applied to the numbers in Table V. the correction at the principal points are found to be

118, 153, 106, 113, 134, 110, 110, 60, and 10,

as given by the three Gay-Lussac curves, and

121, 156, 109, 117, 138, 113, 112, 61, and 10

by the Thiesen curve.

As these nowhere differ by more than 0·004, and by that only near a point where the Thiesen curve is certainly in error (116°), and as they nowhere differ from the results given by Bessel's curve by more than 0·005, except at 136, where the cause of the difference has been explained, it follows that both methods attain the second standard of accuracy. The three Gay-Lussac curves would involve altogether sixty thread-measurements; the Thiesen and two Gay-Lussac curves would involve 104, so that on the whole it would seem better to adopt the former plan, and if when the calculation is concluded there seems any reason to doubt the result, to make another Gay-Lussac correction-curve, and include it in obtaining the final results.

The general result of the investigation may, therefore, be summed up as follows—that labour is saved, and equal accuracy is obtained, by the repetition of the simplest method of correction (Gay-Lussac's) instead of the employment of more elaborate and, theoretically, more perfect schemes.

Part II.

Details of Calculations, with Examples of each Method.

(21) The following system of symbols will be adopted.

The upper and initial points of a thread will be indicated by the letters u and i.

An uncorrected thread-length is therefore $u - i$, indicated by t.

The corrections at any point x to the first, second, &c., degrees of approximation are indicated by $\phi_1(x)$, $\phi_2(x)$, &c. Since the calculations often give the differences between these quantities, it is convenient to define

$$\phi'(x) = \phi_2(x) - \phi_1(x)$$
$$\phi''(x) = \phi_3(x) - \phi_2(x),$$

and so on.

A corrected thread-length is indicated by T, which is defined by the equation

$$T = u + \phi(u) - (i + \phi(i))$$

In principal point methods it is convenient to follow Thiesen (*loc. cit.*) in the use of the symbol δ, such that

$$\delta(x+1) = \phi(x+1) - \phi(x),$$

where the symbols on the right refer to the $\overline{x+1}^{\text{th}}$ and x^{th} principal points respectively.

In cases where the true positions of the thread-ends are not coincident with their theoretical positions, the latter are often indicated by u and i, the actual positions by $u + \Delta u$, and $i + \Delta i$.

When in a step-by-step method the correction is referred to the mean point between the positions of the upper end of the thread and that of the lower end, when next shifted, that mean point may be indicated by $\bar{u}$.

The symbol τ indicates the transferred thread-length defined in Part I. (p. 150) by the equation.

$$\tau = t + \left\{ \phi(u + \Delta u) - \phi(u) - [\phi(i + \Delta i) - \phi(i)] \right\}.$$

In the case of principal point methods it is often best to indicate the position of a thread by reference to the principal points nearest to which its extremities lie. Let the principal points be numbered from o upwards in the direction of increasing scale readings, and let u' and i' be the numbers indicating the principal points nearest to the upper and lower ends of the thread respectively. By the substitution of these quantities for u and i the above system of symbols will apply without further change. In cases, therefore, where ambiguity might otherwise arise, 1′, 2′, &c. mean not the first, second, &c. scale division or degree, but the principal points numbered 1, 2, &c. Where no ambiguity is to be feared the dashes may be dispensed with.

Gay-Lussac's Method.

Thermometer C.

(22) The following is an example of as accurate a compliance with the strict conditions of this method as is possible with Mr. Brown's instrument.

The lower end of the thread was always moved into the same division and generally into the same part of that division as that in which the upper end previously lay. The correction is applied to the mean of these two positions. The thread-length was always measured twice in each position, together with the lengths of the divisions in which the extremities lay. The length of each division was therefore measured four times, twice when the upper and twice when the lower end of the thread lay in it. The mean of these four readings, which rarely differed by more than 0°·003, was taken as the true length.

In Table VII., Columns I. and II. give the positions in terms of uncorrected scale-divisions of the lower and upper ends of the thread. Column III. gives the differences between these quantities or the uncorrected thread-lengths (t).

Hence, if the successive values of t be indicated by t_1, t_2, &c., and if T be the corrected thread-length

$$(1)\begin{cases} T - t_1 = \phi(99{\cdot}66) - \phi(98{\cdot}05) = \delta(99{\cdot}66), \\ T - t_2 = \phi(101{\cdot}27) - \phi(99{\cdot}66) = \delta(101{\cdot}27), \\ T - t_3 = \phi(102{\cdot}89) - \phi(101{\cdot}27) = \delta(102{\cdot}89), \end{cases}$$

and so on.

If, therefore, $\phi(98{\cdot}05) = 0$,

$$\phi(99{\cdot}66) = \delta(99{\cdot}66),$$
$$\phi(101{\cdot}27) = \delta(101{\cdot}27) + \delta(99{\cdot}66),$$

and so on.

Now there are 26 of the equations (1), and addition gives

$$26\,T - (t_1 + t_2 + \ldots\ldots + t_{26}) = \phi(141{\cdot}85) - \phi(98{\cdot}05).$$

But the corrections of these two points may be taken as zero. Hence T is the mean of the uncorrected thread-lengths.

In Column IV., therefore, are the means of the readings in Columns I. and II., or the points to which the corrections are to be applied ($\bar{u}$). In Column V. are the values of $\delta(\bar{u})$ obtained by subtracting each of the numbers in III. from their mean.

In Column VI. are the values of $\phi(\bar{u})$ obtained by taking the sum of all the δ's up to $\delta(\bar{u})$.

TABLE VII.

I.	II.	III.	IV.	V. In terms of 0°·001	VI.
i	u	t	$\bar{u}$	$\delta(\bar{u})$	$\phi(\bar{u})$
98·048	99·656	1·608	99·66	55·9	55·9
99·663	101·269	06	101·27	57·9	113·8
101·274	102·891	17	102·89	46·9	160·7
102·893	104·522	29	104·55	34·9	195·6
104·571	106·219	48	106·23	15·9	211·5
106·250	107·909	59	107 93	4·9	216·4
107·947	109·625	78	109·65	−14·1	202·3
109·667	111·367	1·700	111·37	−36·1	166·2
111·378	113·046	1·668	113 05	−4·1	162 1
113·058	114·723	65	114·75	−1·1	161·0
114·781	116·443	62	116·45	1·9	162·9
116·462	118·120	58	118·14	5·9	168·8
118·159	119·814	55	119·84	8·9	177·7
119 865	121·526	61	121·54	2·9	180·6
121·560	123·247	87	123·25	−23·1	157·5
123·262	124·939	77	124·95	−13·1	144·4
124·959	126 628	69	126·62	−5·1	139·3
126·623	128·279	56	128·28	7 9	147·2
128·278	129·964	86	129 96	−22·1	125·1
129·949	131·640	91	131·65	−27·1	98·0
131·663	133·357	94	133·35	−30·1	67·9
133·350	135·050	1·700	135·05	−36·1	31·8
135·057	136·710	1·653	136·75	10·9	42·7
136·789	138·451	62	138·46	1·9	44·6
138·462	140·144	82	140·15	−18·1	26·5
140·157	141·847	90	141·85	−26·1	·4
		T = 1·6639			

In order to obtain a standard curve from the numbers given in the above Table, a few points were plotted down in the neighbourhood of 100° and 140°, and the curve drawn through them.

The corrections at these points were 0°·069 and 0°·028 respectively, i.e. in the notation used above (p. 147)

$$\phi\,(1) = 0·069, a = -\,0·041, \frac{a}{N} = -\,0·001025.$$

The largest value of $\phi(x) = 0·216$. Hence the largest value of

$$\frac{a}{N}\{\phi(x) - \phi(1)\} \text{ is } -\,0·001 \times 0·188 = -\,0·0002,$$

which is negligible, as is the largest value of $\frac{a^2}{N^2}x$.

Hence the formula reduces to

$$x + \phi(x) - \phi(1) - \frac{a}{N}x = x + \phi(x) - 0·069 + ·001025\,x.$$

The ordinates of the standard curve are therefore easily obtained by subtracting 0·069 from the numbers in Column VI. of the above Table VII., and adding the number of degrees above 100 in Column IV. multiplied by ·001025.

It is unnecessary to give the whole of the remainder of the calculations; but, as examples, the corrections for 104·55 and 135·05 may be taken, all the numbers being in terms of 0°·001:—

$$\phi\,(104{\cdot}55) = 195{\cdot}6 - 69 + 4{\cdot}6 = 131$$
$$\phi\,(135{\cdot}05) = 31{\cdot}8 - 69 + 35{\cdot}1 \times 1{\cdot}025$$
$$= 31{\cdot}8 - 69 + 36 = -1 \text{ approximately.}$$

The standard curve thus obtained is the dotted curve in Plate I. fig. 1.

Gay-Lussac.—Example II.

Used as a principal point method with second approximation.

Thermometer C.

(23) Another example of the application of Gay-Lussac's method was carried out in a somewhat different way.

It was now used to determine the corrections of points 2° apart—i.e. as a principal point method.

The thread-ends always lay in the divisions next to the principal point, and as a first approximation the differences between the corrections at the extremities of the thread and at the principal points were neglected.

The calculation for the first approximation is carried out exactly as in the last case. There were twenty-one principal points—viz. 100°, 102°, 104°, &c. These were numbered from 0 to 20, as shown in the Column headed u' in Table VIII. Columns I. and II. give the positions of the upper and lower ends of the thread; Column III. their differences, or the uncorrected thread-lengths; Columns IV. and V. the values of $\delta\ (u')$ and $\phi\ (u')$ obtained exactly as in the last example:—

With these values of $\phi\ (u')$ an approximate correction curve was drawn, and the corrections for the positions of the upper and lower ends of the thread were taken out in Table IX., Columns I. and II.

Then, since the corrected thread-length

$$= t_1 + \phi\ (u + \Delta u) - \phi\ (i + \Delta i),$$

the differences of the numbers in Columns II. and I. are entered in III., and these, when added to the corresponding numbers in Column III., Table VIII., give the corrected thread-lengths entered in Table IX., Column IV. The numbers in Columns V. and VI. are obtained exactly like those in Columns IV. and V. in Table I.; and, by adding the values of $\phi'\ (u')$ in Table II. Column VI. to those of $\phi\ (u')$ in Column V. Table I., the values of $\phi_2\ (u')$ are found.

It will be noticed that the differences between the values of $\phi\ (u')$ and $\phi_2\ (u')$ are not inconsiderable.

The curve obtained is drawn in Plate I. fig. 1. It is used, hereafter, as a first approximation curve for obtaining transferred thread-lengths in the other methods.

Table VIII.

(1st Approximation.) Corrections in terms of 0°·001.

u'	I* $i' + \Delta i'$	II* $u' + \Delta u'$	III. t	IV. $\delta(u')$	V. $\phi(u')$
1	0·036	1·908	1·872	·0754	75·4
2	2·050	3·958	1·908	·0394	114·8
3	4·049	5·969	1·920	·0274	142·2
4	6·021	7·962	1·941	·0064	148·6
5	8·024	9·985	1·961	–·0136	135·0
6	9·978	11·958	1·980	–·0326	102·4
7	12·026	13·966	1·940	·0074	109·8
8	14·012	15·958	1·946	·0014	111·2
9	16·012	17·949	1·937	·0104	121·6
10	18·050	19·988	1·938	·0094	131·0
11	20·034	21·978	1·944	·0034	134·4
12	22·036	24·011	1·975	–·0276	106·8
13	24·015	25·968	1·953	–·0056	101·2
14	26·044	27·985	1·941	·0064	107·6
15	28·060	30·031	1·971	–·0236	84·0
16	29·971	31·948	1·977	–·0296	54·4
17	31·957	33·941	1·984	–·0366	17·8
18	34·030	35·987	1·957	–·0096	8·2
19	36·011	37·951	1·940	·0074	15·6
20	38·028	39·991	1·963	–·0156	0·0

T = 1·9474.

* The numbers in these columns are diminished by 100, thus 2·05 means 102·05.

Table IX. (Second Approximation.)

	I.	II.	III.	IV.	V.	VI.	VII.
u'	Corrections from first curve (in ·001°) $\phi(i' + \Delta i')$	$\phi(u' + \Delta u')$	Corrections of thread-lengths.	Thread-lengths corrected.	$\delta'(u')$	$\phi'(u') = \phi_2(u') - \phi(u')$	$\phi_2(u')$
1	2	72	70	1·942	4·9	4·9	80
2	76	115	39	47	– ·1	4·8	120
3	117	142	25	45	1·9	6·7	149
4	143	149	6	47	– ·1	6·6	155
5	149	135	– 14	47	– ·1	6·5	142
6	135	102	– 33	47	– ·1	6·4	109
7	102	110	8	48	– 1·1	5·3	115
8	110	111	1	47	– ·1	5·2	116
9	111	121	10	47	– ·1	5·1	127
10	122	131	9	47	– ·1	5·0	136
11	132	134	2	46	·9	5·9	140
12	134	107	– 27	48	– 1·1	4·8	112
13	107	101	– 6	47	– ·1	4·7	106
14	101	108	7	48	– 1·1	3·6	111
15	108	83	– 25	46	·9	4·5	89
16	85	54	– 31	46	·9	5·4	60
17	54	19	– 35	49	– 2·1	3 3	21
18	17	8	– 9	48	– 1·1	2·2	10
19	8	17	9	49	– 2·1	·1	16
20	16	0	– 16	47	– ·1	0·0	0

T_2 = 1·9469

Gay-Lussac.—Example III.

Application of method of transference.

Determination of secondary points.

(24) In this case a thread about 4° long was used, and the principal points were taken 4° apart. The thread having been accurately broken off, the transfer corrections are small. The curve determined in the last example was used as an approximation to determine them. The positions of the upper and lower ends are given in Columns II. and I. Table X.; their difference, or the uncorrected thread-length, in Column III. From this the transferred thread-length

$$\tau = t + (\phi\ (u + \Delta u) - \phi\ (u)) - (\phi\ (i + \Delta i) - \phi\ (i)),$$

is calculated in Columns IV., V., and VI., and from these the corrections of the principal points are determined as before.

This example offers a means of illustrating the determination of secondary points. Let P_0 and P be two principal points between which n secondary points are to be determined. This may be done by applying Gay-Lussac's method to the interval by means of a thread=one $\overline{n+1}^{\text{th}}$ of the distance between P_0 and P_1. If this thread has been used to determine an approximate correction curve, transferred thread-lengths can be used, and the equations

$$\begin{aligned} T - \tau_1 &= \phi\ (1) - \phi\ (P_0) \\ T - \tau_2 &= \phi\ (2) - \phi\ (1) \\ T - \tau_3 &= \phi\ (3) - \phi\ (2) \\ \&c. &= \&c. \\ T - \tau_{n+1} &= \phi\ (P_1) - \phi\ (n) \end{aligned}$$

give by addition

$$\begin{aligned} (n + 1)\, T &= \tau_1 + \tau_2 + \tau_3 + \cdot \quad + \tau_{n+1} + \phi\ (P_1) - \phi\ (P_0) \\ &= \tau_1 + \tau_2 + \tau_3 + \quad + \tau_{n+1} + \delta\ (P_1). \end{aligned}$$

Whence T can be determined, and the calculations proceed exactly as before, except that T is not the mean of the transferred thread-lengths. The calculations of a few points will suffice, the thread used in Example II. being employed to bisect the intervals between the principal points obtained in the present example.

Thus in Table XI., Column I. gives the principal and secondary points numbered as in Table VIII., Example 2. Column II. gives the uncorrected thread-lengths taken from the same Table. Columns III. and IV. give the values of the quantities by which the transference is effected, taken from the continuous curve in Plate I., fig. 1. Column VI. gives the value s of δ correct to 0·001 taken from Table X., Column VII. Column VII. gives the values of T, i.e. of $\frac{1}{2}\{\tau_1 + \tau_2 + \delta(P_1)\}$. Column VIII. gives $T - \tau$, and in Column IX. the corrections are finally obtained, as given by the formula.

The points given by this thread are indicated in Plate I., fig. 1.

TABLE X.

	I.	II.	III.	IV.	V.	VI.	VII.	VIII.
u	$i + \Delta i$	$u + \Delta u$	t	$\phi(i + \Delta i) - \phi(i)$	$\phi(u + \Delta u) - \phi(u)$	τ	$\delta(\bar{u})$ In terms of 0·001	$\phi(\bar{u})$
104	100·010	104·006	3·996	—	—	3·996	115·6	115·6
8	3·959	8·034	4·075	−0·001	—	4·076	35·6	151·2
12	7·972	12·132	4·160	—	−0·001	4·159	−47·4	103·8
16	12·017	16·119	4·102	—	—	4·102	9·6	113·4
20	15·975	20·065	4·090	—	—	4·090	21·6	135·0
24	20·014	24·151	4·137	—	−0·001	4·136	−24·4	110·6
28	24·013	28·124	4·111	—	—	4·111	+·6	111·2
32	28·013	32·177	4·164	—	−0·002	4·162	−50·4	60·8
36	32·025	36·184	4·159	−0·001	—	4·160	−48·4	12·4
40	36·010	40·135	4·125	—	−0·001	4·124	−12·4	0·0
—	—	—	—	—	—	4·1116	—	—

TABLE XI.

I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.
u'	t	$\phi(i' + \Delta i') - \phi(i')$	$\phi(u' + \Delta u') - \phi(u')$	τ	$\delta(P_1)$	$T = \frac{1}{2}\left\{\tau_1 + \tau_2 + \delta(P_1)\right\}$	$T - \tau_1$	$T - \tau_1 +$ [illegible] $\phi(P_0)$
1	1·872	0·001	−0·002	(τ_1) 1·869	116	1·946	·077	·077
2	1·908	0·001	0·	(τ_2) 1·907				
3	1·920	0·001	0·	(τ_1) 1·919	36	1·948	·029	·145
4	1·941	0·	0·	(τ_2) 1·941				
5	1·961	&c.	&c.	&c.				

Hällström's Method.

Thermometer C.

(25) In the application of Hällström's method the principal points were taken 4° apart, and a thread about 8° long was measured with its lower point in the neighbourhood of each of them, and a thread about 12° long, with its lower end in the neighbourhood of the first two. S and σ have with respect to this longer thread the same meanings as T and τ for the shorter. The Gay-Lussac curve drawn in a continuous line in Plate I., fig. 1, was used to effect the transference. Then the following equations were obtained:—

$$
\begin{aligned}
S &= \sigma_3 + \phi(3') - \phi(0) \quad . \quad . \quad . \quad . \quad (1)\\
S &= \sigma_4 + \phi(4') - \phi(1') \quad . \quad . \quad . \quad . \quad (2)\\
T &= \tau_2 + \phi(2') - \phi(0) \quad . \quad . \quad . \quad . \quad (3)\\
T &= \tau_3 + \phi(3') - \phi(1') \quad . \quad . \quad . \quad . \quad (4)\\
\&c. &= \&c.\\
T &= \tau_{10} + \phi(10') - \phi(8') \quad . \quad . \quad . \quad . \quad (11)
\end{aligned}
$$

Hence, remembering that $\delta(n) = \phi(n) - \phi(n - {}_1)$ from (1) and (2).

$$
\begin{aligned}
\sigma_3 - \sigma_4 &= \delta(4') - \delta(1')\\
\therefore \delta(4') &= \delta(1') + \sigma_3 - \sigma_4\\
&= \delta(1') + \gamma(4') \text{ say}
\end{aligned}
$$

Similarly from the other equations:—

$$\tau_2 - \tau_3 = \delta(3') - \delta(1') \therefore \delta(3') = \delta(1') + \tau_2 - \tau_3 = \delta(1') + \gamma(3') \text{ say}$$

$$
\begin{aligned}
\tau_3 - \tau_4 = \delta(4') - \delta(2') \therefore \delta(2') &= \delta(4') - (\tau_3 - \tau_4)\\
&= \delta(1') + \sigma_3 - \sigma_4 - (\tau_3 - \tau_4)\\
&= \delta(1') + \gamma(2') \text{ say}
\end{aligned}
$$

Similarly all the other δ's can be expressed in terms of $\delta(1')$. If $\phi(0')$ and $\phi(10')$ are taken = zero,

$$\delta(1') + \delta(2') + \qquad + \delta(10') = 0.$$

Table XII.

Thread I.

I.	II.	III.	IV. In ·001°	V.	VI.
100·022	111·767	11·745	+1	+2	11·746
4·015	15·874	11·859	0	0	11·859

Thread II.

I.	II.	III.	IV.	V.	VI.
0·020	7·688	7·668	+1	+1	7·668
4·019	11·852	7·833	0	+1	7·834
8·019	15·878	7·859	0	0	7·859
12·017	19·808	7·791	0	0	7·791
16·030	23·854	7·824	0	+2	7·826
20·025	27·869	7·844	0	0	7·844
24·013	31·885	7·872	0	+2	7·874
28·015	35·937	7·922	0	0	7·922
32·014	39·890	7·876	0	+1	7·877

Hence, if all the nine equations which give the δ's in terms of $\delta(1')$ be added, it follows that

$$-10\,\delta(1') = \gamma(2') + \gamma(3') + \qquad + \gamma(10').$$

Hence, $\delta(1')$ is known, from it all the other δ's can be deduced, and the corrections at the principal points are obtained at once from the equation

$$\phi(n') = \delta(1') + \delta(2') + \quad + \delta(n').$$

Table XII. gives the calculations necessary for finding the transferred thread-lengths. Columns I. and II. give the positions of the lower and upper ends of the thread. Column III. the uncorrected thread-lengths. Columns IV. and V. give the values of $\phi(i' + \Delta i') - \phi(i')$ and $\phi(u' + \Delta u') - \phi(u')$. Column VI. gives the transferred thread-length obtained by adding V. to III. and subtracting IV.

Table XIII. gives the details of the determination of all the δ's in terms of $\delta(1')$.

Column II. gives the transferred thread-lengths when the upper ends lie near the principal points indicated in Column I.

Column III. contains the values of $\sigma_3 - \sigma_4$, $\tau_2 - \tau_3$, $\tau_3 - \tau_4$, and so on.

Column IV. contains the equations between the δ's obtained as above.

In Column V. the right-hand sides are transformed so as to contain $\delta(1')$ and constants only.

TABLE XIII.

I. u'	II. σ or τ	III. In ·001°	IV.	V.
3′	11·746	—	—	—
4′	11·859	− 113	$\delta(4') = \delta(1') - 113$	$= \delta(1') - 113$
2′	7·668	—	—	—
3′	7·834	− 166	$\delta(3') = \delta(1') - 166$	$= \delta(1') - 166$
4′	7·859	− 25	$\delta(2') = \delta(4') + 25$	$= \delta(1') - 88$
5′	7·791	68	$\delta(5') = \delta(3') + 68$	$= \delta(1') - 98$
6′	7·826	− 35	$\delta(6') = \delta(4') - 35$	$= \delta(1') - 148$
7′	7·844	− 18	$\delta(7') = \delta(5') - 18$	$= \delta(1') - 116$
8′	7·874	− 30	$\delta(8') = \delta(6') - 30$	$= \delta(1') - 178$
9′	7·922	− 48	$\delta(9') = \delta(7') - 48$	$= \delta(1') - 164$
10′	7·877	45	$\delta(10') = \delta(8') + 45$	$= \delta(1') - 133$
				$10\,\delta(1') = 1204$

TABLE XIV.

I. u'	II. $\delta(u')$	III. $\phi(u')$
1′	120·4	120·4
2′	32·4	152·8
3′	− 45·6	107·2
4′	7·4	114·6
5′	22·4	137·0
6′	− 27·6	109·4
7′	4·4	113·8
8′	− 57·6	56·2
9′	− 43·6	12·6
10′	− 12·6	·0

The value of $\delta(1')$ obtained by dividing the sum of the constants by − 10 is found to be 120·4.

Using this number, the values of $\delta(u')$ are found in Table XIV., Column II., whence in Column III. the corrections for the principal points are found in the usual way.

THIESEN'S METHOD.

Thermometer C.

(26) If the principal points be numbered from 0 to n, Herr Thiesen employs a series of threads, the lengths of which are approximately equal to 1, 2, . . $n-1$ times the distance between two consecutive principal points. He deals with untransferred thread-lengths. In the following example, however, transferred thread-lengths have been used, but as the method of transference has been fully illustrated, it is unnecessary to exhibit the calculations. Each thread gives a number of equations of the form

$$(1)\qquad \begin{aligned} T &= \tau_{u'} + \phi(u') - \phi(0) \\ T &= \tau_{u'+1} + \phi(u+1) - \phi(1') \\ T &= \tau_{u'+2} + \phi(u+2) - \phi(2') \end{aligned}$$

and so on.

By subtracting each equation from that which precedes it, the following are obtained :—

$$(2)\qquad \begin{aligned} \tau_{u'+1} - \tau_{u'} &= \delta(1') - \delta(u'+1) \\ \tau_{u'+2} - \tau_{u'+1} &= \delta(2') - \delta(u'+2) \end{aligned}$$

and so on.

Now, the thread whose length is equal to the distance between two principal points can be measured in n positions, and hence from it $n-1$ equations of the series (2) can be obtained. Similarly, the thread the length of which is twice the distance between consecutive principal points gives $n-2$ equations ; and in all there are

$$\overline{n-1} + \overline{n-2} + \ldots . + 1 = \frac{n(n-1)}{2}$$

equations between the δ's.

These are combined to find their values as follows.

A table is prepared, of which the following is a symbolical representation :—

i'	$u' = 1'$	$2'$	$3'$	&c.
$1'$ $2'$ $3'$ $\vdots$ n'	$\delta(1') - \delta(1')$ $\delta(1') - \delta(2')$ $\delta(1') - \delta(3')$ $\vdots$ $\delta(1') - \delta(n')$	$\delta(2') - \delta(1')$ $\delta(2') - \delta(2')$ $\delta(2') - \delta(3')$ $\vdots$ $\delta(2') - \delta(n')$	$\delta(3') - \delta(1')$ &c.	&c.
—	$S(1')$	$S(2')$	$S(3')$	&c.

The differences of the δ's are given by equations (2). On adding all the numbers in any column, say the r^{th}, an expression of the form

$$n\delta(r') - \{\delta(1') + \delta(2') + \quad + \delta(n')\} = S(r')$$

is obtained. But if $\phi(0') = \phi(n') = 0$, the expression in the bracket vanishes, and hence $n\delta(r') = S(r')$.

The δ's being known, the values of ϕ may be found as usual.

TABLE XV.

i'	I. τ	II. In ·001°	u'
	Thread I.		
0	3·996		1
1	4·076	− 80	2
2	4·159	− 83	3
3	4·102	57	4
4	4·090	12	5
5	4·136	− 46	6
6	4·111	25	7
7	4·161	− 50	8
8	4·160	1	9
9	4·123	37	10
	Thread II.		
0	7·668		2
1	7·834	−166	3
2	7·859	− 25	4
3	7·791	68	5
4	7·826	− 35	6
5	7·844	− 18	7
6	7·874	− 30	8
7	7·922	− 48	9
8	7·877	45	10
	Thread III.		
0	11·746		3
1	11·859	−113	4
2	11·874	− 15	5
3	11·852	22	6
4	11·862	− 10	7
5	11·932	− 70	8
6	11·956	− 24	9
7	11·968	− 12	10
	Thread IV.		
0	15·935		4
1	16·037	−102	5
2	16·097	− 60	6
3	16·046	51	7
4	16·103	− 57	8
5	16·183	− 80	9
6	16·164	19	10
	Thread V.		
0	19·640		5
1	19·778	−138	6
2	19·815	− 37	7
3	19·823	− 8	8
4	19·881	− 58	9
5	19·908	− 27	10
	Thread VI.		
0	23·991		6
1	24·118	−127	7
2	24·195	− 77	8
3	24·202	− 7	9
4	24·220	− 18	10
	Thread VII.		
0	27·775		7
1	27·953	−178	8
2	28·034	− 81	9
3	27·995	39	10
	Thread VIII.		
0	32·661		8
1	32·838	−177	9
2	32·887	− 49	10

In the example worked out, the lengths of the thread employed were approximately 4°, 8°, 12° . . 32°. In strict accordance with the method as just explained, a thread 36° long ought also to have been used. It was, however, found difficult to manipulate so long a thread. Herr Thiesen points out that a number of threads less than the largest possible number may be used, and the plan adopted below can easily be extended in a case where more than one thread is wanting.

Table XV. gives in the first and last columns the numbers of the principal points between which the thread was measured. Column I. gives the transferred thread-lengths, Column II. the differences between the consecutive values of τ.

Thus, Thread I. gives in accordance with equations (2)

$$\delta\,(2') - \delta\,(1') = -\,80$$
$$\delta\,(3') - \delta\,(2') = -\,83, \&c.$$

Thread II. gives

$$\delta\,(3') - \delta\,(1') = -\,166$$
$$\delta\,(4') - \delta\,(2') = -\,25, \&c.$$

These numbers are tabulated in Table XVI.

Thus $\delta\,(2') - \delta\,(1')$ is entered in Column 2, Row 1.

„ $\delta\,(3') - \delta\,(2')$ „ „ 3, „ 2.

and so on.

TABLE XVI.—Values of $\delta\,(u') - \delta\,(i')$ in terms of ·001°.

i'	$u'=1$	2	3	4	5	6	7	8	9	10
1	0	−80	−166	−113	−102	−138	−127	−178	−177	
2	80	0	− 83	− 25	− 15	− 60	− 37	− 77	− 81	−49
3	166	83	0	57	68	22	51	− 8	− 7	39
4	113	25	− 57	0	12	− 35	− 10	− 57	− 58	−18
5	102	15	− 68	− 12	0	− 46	− 18	− 70	− 80	−27
6	138	60	− 22	35	46	0	25	− 30	− 24	19
7	127	37	− 51	10	18	− 25	0	− 50	− 48	−12
8	178	77	8	57	70	30	50	0	1	45
9	177	81	7	58	80	24	48	− 1	0	37
10		49	− 39	18	27	− 19	12	− 45	− 37	0
S (u')	1081	347	−471	85	204	−247	− 6	−516	−511	34
$\delta\,(u')$	121·2	34·7	−47·1	8·5	20·4	−24·7	− 0·6	−51·6	−51·1	−9·7
$\phi\,(u')$	121·2	155·9	108·8	117·3	137·7	113	112·4	60·8	9·7	

It will be seen that the squares in Column 10, Row 1, and Column 1, Row 10, are blank. This results from the fact that no measures were taken with a thread 36° long.

By adding the numbers in the different columns, the values of all the δ's, except δ (1) and δ (10) are found as previously explained.

By adding Column I., however, the equation,

$$9\,\delta\,(1') - \{\delta\,(1') + \delta\,(2') + \quad + \delta\,(9')\} = 1081$$

is obtained, or

$$9\,\delta\,(1') + \delta\,(10') = 1081.$$

Similarly, Column 10 gives

$$9\,\delta\,(10') + \delta\,(1') = 34.$$

Whence $\delta\,(1') = 121{\cdot}2 \quad \delta\,(10') = -\,9{\cdot}7.$

Mârek's Method.

Thermometer C.

(27) Thiesen's method supplies, as has already been shown, more equations than there are unknown quantities. Mârek has, therefore, applied the method of least squares to measurements made in this way up to and including the case in which the tube is divided into six intervals.

As the formulæ are somewhat lengthy, those only will be given which suffice for the correction of four points. First, let the tube be divided into five parts by principal points numbered from 0 to 5 (in this case the dashes will be omitted). Let τ_{ui} be the transferred thread-length measured between the u^{th} and i^{th} principal points of a thread equal approximately to the interval between them, and let the measurements be made as in Thiesen's method, and let threads equal to 1, 2, 3, and 4 intervals be measured with their lower ends at as many principal points as possible.

Finally, let $\phi(0) = \phi(5) = 0$, then

$$\begin{aligned}
-\ \ 30\,\phi(1) &= -\tau_{54} - \tau_{43} - \tau_{32} - 6\tau_{21} + 9\tau_{10} - 5\tau_{31} + 5\tau_{20} \\
&\quad - 5\tau_{41} + 5\tau_{30} - 5\tau_{51} + 5\tau_{40}; \\
-240\,\phi(2) &= -16\tau_{54} - \tau_{43} - 46\tau_{32} + 39\tau_{21} + 24\tau_{10} - 15\tau_{53} \\
&\quad - 45\tau_{42} - 5\tau_{31} + 65\tau_{20} - 45\tau_{52} + 10\tau_{41} \\
&\quad + 35\tau_{30} - 20\tau_{51} + 20\tau_{40}; \\
-240\,\phi(3) &= -24\tau_{54} - 39\tau_{43} + 46\tau_{32} + \tau_{21} + 16\tau_{10} - 65\tau_{53} \\
&\quad + 5\tau_{42} + 45\tau_{31} + 15\tau_{20} - 35\tau_{52} - 10\tau_{41} + 45\tau_{30} \\
&\quad - 20\tau_{51} + 20\tau_{40}; \\
-\ \ 30\,\phi(4) &= -9\tau_{54} + 6\tau_{43} + \tau_{32} + \tau_{21} + \tau_{10} - 5\tau_{53} + 5\tau_{42} - 5\tau_{52} \\
&\quad + 5\tau_{41} - 5\tau_{51} + 5\tau_{40}.
\end{aligned}$$

In applying these formulæ to Thermometer C the principal points would be 100°, 108°, 116°, &c. Hence, taking from the tables of thread-lengths given in Thiesen's methods those which are multiples of 8° in length, and which are measured with their lower ends at their principal point, the following values are obtained:—

$\tau_{54} = 7{\cdot}877$.	$\tau_{53} = 16{\cdot}164$.	$\tau_{52} = 24{\cdot}220$
$\tau_{43} = 7{\cdot}874$.	$\tau_{42} = 16{\cdot}103$.	$\tau_{41} = 24{\cdot}195$
$\tau_{32} = 7{\cdot}826$.	$\tau_{31} = 16{\cdot}097$.	$\tau_{30} = 23{\cdot}991$
$\tau_{21} = 7{\cdot}859$.	$\tau_{20} = 15{\cdot}935$	
$\tau_{10} = 7{\cdot}668$		$\tau_{51} = 32{\cdot}887$
		$\tau_{40} = 32{\cdot}661$;

whence, from the above formulæ,

$$\phi(0) = 0,\ \phi(1) = 156,\ \phi(2) = 116,\ \phi(3) = 112,\ \phi(4) = 62,\ \phi(5) = 0.$$

If it be required to halve these intervals a thread about 4° long must be used, and the calculations are exactly similar to those given in the third example of Gay-Lussac's method.

Let P_1 and P_0 be any two of the principal points where corrections $\phi(P_1)$ and $\phi(P_0)$ have just been determined. Let τ_1, τ_2 be the transferred thread-lengths of a thread about 4° long, measured with its lower and upper ends near each of them in turn, and then the correction for the point half-way between them is

$$\tfrac{1}{2}\{\tau_2 - \tau_1 + \phi(P_1) + \phi(P_0)\}.$$

Table XIX. Thermometer C.

Uncorrected Thread-lengths u_{kr}.

0	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.	h_r
98	7·679	9·578	13·242	15·599	16·669	19·127	20·487	22·198	24·361	25·281	17·4221
100	7·733	9·655	13·308	15·667	16·730	19·183	20·544	22·271	24·456	25·366	17·4913
102	7·836	9·773	13·385	15·733	16·796	19·251	20·635	22·376	24·529	25·439	17·5753
104	7·909	9·807	13·417	15·763	16·825	19·308	20·697	22·416	24·577	25·498	17·6217
106	7·931	9·833	13·435	15·779	16·868	19·353	20·731	22·439	24·635	25·554	17·6558
108	7·933	9·826	13·437	15·816	16·892	19·354	20·728	22·483	24·665	25·600	17·6734
110	7·908	9·807	13·446	15·812	16·879	19·356	20·750	22·492	24·694	25·613	17·6757
112	7·864	9·765	13·426	15·771	16·845	19·351	20·739	22·504	24·659	25·558	17·6482
114	7·864	9·804	13·434	15·797	16·887	19·392	20·790	22·509	24·665	25·581	17·6723
116	7·896	9·813	13·448	15·834	16·915	19·422	20·786	22·507	24·688	25·613	17·6922
v^k =	7·8553	9·7661	13·3978	15·7571	16·8306	19·3097	20·6887	22·4195	24·5929	25·5103	m = 17·6128

Table XX.

Uncorrected Thread-lengths (Additional measures).

0	I.	II.	III.	IV.	V.	VI.	VII.	VIII.
118	7·917	9·820	13·485	15·878	16·969	19·427	20·800	22·540
120	7·918	9·847	13·537	15·898	16·960	19·437	20·831	
122	7·947	9·878	13·556	15·897	16·967	19·466		
124	7·949	9·889	13·520	15·872	16·968			
126	7·976	9·896	13·526	15·909				
128	7·997	9·895	13·556					
130	7·964	9·890						
132	7·952	9·888						
134	7·943							

TABLE XXI.

Scale Readings for Upper Ends of Threads diminished by 100.

0	I.	II.	III	IV.	V.	VI.	VII.	VIII.	IX.	X.
98	5·679	7·578	11·242	13·599	14·669	17·127	18·487	20·198	22·361	23·281
100	7·733	9 655	13·308	15·667	16·730	19·183	20·544	22·271	24·456	25·366
102	9·836	11·773	15·385	17·733	18·796	21·251	22·635	24·376	26·529	27·439
104	11·909	13·807	17·417	19·763	20·825	23·308	24·697	26·416	28·577	29·498
106	13·931	15·833	19·435	21·779	22·868	25·353	26·731	28·439	30·635	31·554
108	15·933	17·826	21·437	23·816	24·892	27·354	28·728	30·483	32·665	33·600
110	17·908	19·807	23·446	25·812	26·879	29·356	30·750	32·492	34·694	35·613
112	19·864	21·765	25·426	27·771	28·845	31·351	32·739	34·504	36·659	37·558
114	21·864	23·804	27·434	29·797	30·887	33·392	34·790	36·509	38·665	39·581
116	23·896	25·813	29·448	31·834	32·915	35·422	36·786	38·507	40·688	41·613

TABLE XXII.

Ditto for Additional Measures.

0 •	I.	II.	III.	IV.	V.	VI.	VII.	VIII.
118	25 917	27·820	31·485	33·878	34·969	37·427	38·800	40·540
120	27·918	29·847	33·537	35·898	36·960	39·437	40·831	
122	29·947	31·878	35·556	37·897	38·967	41·466		
124	31·949	33·889	37·520	39·872	40·968			
126	33·976	35·896	39·526	41·909				
128	35·997	37·895	41·556					
130	37·964	39·890						
132	39·952	41·888						
134	41·943							

let U_{kr} be the number entered in the r^{th} row of the k^{th} column (the 100, which for shortness has been omitted, being of course included).

The symbolical representation of Table XXI., with the V's, &c., introduced, is therefore

0	I.	II.	III.	—	X.	
i_1 i_2 i_{10}	$U_{1,1}$ $U_{1,2}$ $U_{1,10}$	$U_{2,1}$ $U_{2,2}$ $U_{2,10}$	$U_{3,1}$ $U_{3,2}$ $U_{3,10}$	— — —	$U_{10,1}$ $U_{10,2}$ $U_{10,10}$	H_1 H_2 H_{10}
	V_1	V_2	V_3	—	V_{10}	M

where $$M = \frac{V_1 + V_2 + \quad + V_{10}}{10} = \frac{H_1 + H_2 + \quad + H_{10}}{10}.$$

Now, von Oettingen proves (*loc. cit.* p. 9), that

$$\phi U_{kr} = H_r + V_k - M - U_{kr}.$$

An alternative plan is, however, better—viz., to make use of Table XIX. instead of Table XXI., inasmuch as the numbers employed are smaller. Let μ be the mean of the initial points, and let h_r, v_k, m and u_{kr} have the same significations with respect to Table XIX. as the corresponding large letters have to Table XXI. Then

$$H_r = i_r + h_r,\ V_k = \mu + v_k,\ M = \mu + m,\ U_{kr} = i_r + u_{kr}.$$

∴ by substitution in the above formula,

$$\phi\,(U_{kr}) = h_r + v_k - m - u_{kr}.$$

The values of all the four quantities on the right-hand side of this equation are given in Table XIX.

Table XXIII. contains the values of $v_k - u_{kr}$, and in the last column of $h_r - m$.

Table XXIV. is obtained by adding the values of $h_r - m$ to those of $v_k - u_{kr}$—*e.g.* in Column I. 176 − 191 = − 15, and so on.

Table XXIV., therefore, contains the corrections according to the formula for the scale readings given in corresponding situations in Table XXI. A curve is then drawn, with the scale divisions in Column I., Table XXI. as abscissæ, and the corresponding corrections in Column I. Table XXIV. as ordinates, and similar curves are drawn for each of the other threads.

They are shown in fig. 1, Plate II., drawn in continuous lines, and numbered to correspond with the column and thread from which they are deduced. The scale of the curves in the plates is one-half of that actually employed. The mean of the ordinates of these curves for every degree above the highest initial point is then taken, and a curve with these quantities as ordinates is drawn, thus forming part of the *first mean curve*. It is shown in fig. 2, Plate II., drawn in a continuous line. It will be observed that the first correction curves do not extend to the lower end of the scale. The corrections for this are obtained from the initial

Table XXIII.

($v_k - u_{kr}$). *In terms of* 0°·001.

0	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.	$h_r - m$
98	176	188	156	158	162	183	202	222	232	229	−191
100	122	111	90	90	101	127	145	149	137	144	−122
102	19	− 7	13	24	35	59	54	44	64	71	− 38
104	−54	−41	−19	− 6	6	2	− 8	4	16	12	9
106	−76	−67	−37	−22	−37	− 43	− 42	−19	− 42	− 44	43
108	−78	−60	−39	−59	−61	− 44	− 39	−63	− 72	− 90	60
110	−53	−41	−48	−55	−48	− 46	− 61	−72	−101	−103	63
112	− 9	1	−28	−14	−14	− 41	− 50	−84	− 66	− 48	35
114	− 9	−38	−36	−40	−56	− 82	−101	−89	− 72	− 71	59
116	−41	−47	−50	−77	−84	−112	− 97	−87	− 95	−103	79

Table XXIV.

($\phi\, U_{kr} = v_k - u_{kr} + h_r - m$.)

0	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.
98	−15	− 3	−35	−33	−29	− 8	11	31	41	38
100	0	−11	−32	−32	−21	5	23	27	15	22
102	−19	−45	−25	−14	− 3	21	16	6	26	33
104	−45	−32	−10	3	15	11	1	13	25	21
106	−33	−24	6	21	6	0	1	24	1	− 1
108	−18	0	21	1	− 1	16	21	− 3	−12	−30
110	10	22	15	8	15	17	2	− 9	−38	−40
112	26	~~36~~	7	21	21	− 6	−15	−49	−31	−13
114	50	21	23	19	3	−23	−42	−30	−13	−12
116	38	32	29	2	− 5	−33	−18	− 8	−16	−24

points. It is proved by von Oettingen that the correction for an initial point i_r is given by

$$\phi\ (i_r) = \mathrm{H}_r - i_r + \text{constant}$$
$$= h_r + \text{constant}.$$

Now, if the assumption is made that the correction for the highest initial point is accurately given by the first mean curve, the corrections for the initial points are readily found by adding to the values of h_r in Table XIX., or $h_r - m$ in Table XXIII., the quantity which is necessary to make h_{10} or $h_{10} - m$ equal to the correction thus obtained from the curve.

Thus, in the example under discussion, the ordinate of the first mean curve at 116° is $-$ ·024. To make the value of $h_{10} - m$—viz. ·079—equal to this, ·103 must be subtracted from it. Hence the correction for 98° is $-$ ·191 $-$ ·103 = $-$ ·294, and so on. The quantities so obtained are plotted down in fig. 1, Plate II., and produce the first *initial point curve* (P Q R).

In order to combine this with the portions of the upper point correction curves which extend below 116°, von Oettingen gives to it equal weight with them, takes the mean, and thus completes the first approximation correction-curve.

The corrections for the initial points thus determined are inserted in Table XXV. :—

TABLE XXV.

Corrections of initial points expressed in terms of 0°·001 Correction of 116 from fig. 1 = $-$ 24 $h - m$ for 116 . . . = 79			
98	−294	108	−43
100	−225	110	−40
102	−141	112	−68
104	− 94	114	−44
106	− 60	116	−24

TABLE XXVI.

Corrections of Upper Ends from mean curve I. (fig. 2., Plate II.) expressed in terms of 0°·001.

0	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.	$h'r$
98	− 40	−18	−44	−39	−29	−13	2	19	25	20	−11·7
100	− 17	−23	−42	−26	−18	9	22	25	8	8	− 5·4
102	− 24	−48	−27	− 6	5	26	24	8	14	20	− 0·8
104	− 49	−36	−10	15	24	19	8	13	23	17	2·4
106	− 35	−25	11	26	23	8	16	23	5	− 6	4·6
108	− 25	− 5	26	13	7	20	23	6	−14	−25	2·6
110	− 4	15	18	9	17	18	3	−13	−39	−39	− 1·5
112	16	26	8	22	22	− 4	−14	−37	−30	−18	− 0·9
114	26	13	20	14	1	−22	−39	−32	−12	−12	− 4·3
116	12	9	17	− 9	−15	−40	−28	−12	−18	−25	−10·9
v'_k =	−14·0	−9·2	−2·3	1·9	3·7	2·1	1·7	0·0	− 3·8	−6·0m'=	−2·59

TABLE XXVII.

($v'_k - u'_{kr}$) *In thousandths of a degree.*

0	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.	$h'_r - m'$	ϖ_r	$h_r - m' - \varpi_r$	$\phi'(i)$
98	26	9	42	41	33	15	0	−19	−29	−26	−9·	0	−9	−3
100	3	14	40	28	22	−7	−20	−25	−12	−14	−3·	0	−3	3
102	10	39	25	8	−1	−24	−22	−8	−18	−26	·2·	0	2	8
104	35	27	8	−13	−20	−17	−6	−13	−27	−23	·5·	0	5	11
106	21	16	−13	−24	−19	−6	−14	−23	−9	0	7·	25	−18	−12
108	11	−4	−28	−11	−3	−18	−21	−6	10	19	5·	28	−23	−17
110	−10	−24	−20	−7	−13	−16	−1	13	35	33	1·	14	−13	−7
112	−30	−35	−10	−20	−18	6	16	37	26	12	2·	18	−16	−10
114	−40	−22	−22	−12	3	24	41	32	8	6	−2·	10	−13	−7
116	−26	−18	−19	11	19	42	30	12	14	19	−8·	0	−8	−2

TABLE XXVIII.

($\phi'(Ukr) = v'_k - u'_{kr} + h'_r - m'$).

0	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.
98	17	0	33	32	24	6	−9	−28	−38	−35·
100	0	11	37	25	19	−10	−23	−28	−15	−17·
102	12	41	27	10	1	−22	−20	−6	−16	−24·
104	40	32	13	−8	−15	−12	−1	−8	−22	−18·
106	28	23	−6	−17	−12	1	−7	−16	−2	7·
108	16	1	−23	−6	2	−13	−16	−1	15	24·
110	−9	−23	−19	−6	−12	−15	0	14	36	34·
112	−28	−33	−8	−18	−16	8	18	39	28	14·
114	−42	−24	−24	−14	1	22	39	30	6	4·
116	−34	−26	−27	3	11	34	22	4	6	11·

The entire continuous curve in fig. 2, Plate II., made up partly of the initial point curve, partly of the first mean curve, partly of the two combined, is called the first approximation curve.

(30) If a second approximation is required, the theoretical procedure is to insert in Table XXI. the corrected values of the initial and upper points as given by the first mean curve. Hence, to deduce a corrected, Table XIX., and to proceed as before.

A considerable saving of labour can, however, be effected by dealing with the corrections in the quantities in Table XXI. alone, instead of with the quantities themselves.

Thus the corrections for the upper ends of the thread taken from the first approximation curve are entered in Table XXVI.

In Tables XXVII. and XXVIII. the same operations are performed upon these as are performed in Tables XXIII. and XXIV. upon those in Table XIX. Hence a series of numbers are obtained by which the corrections in Table XXIV. would have been altered had the measurements been made with the scale corrected to the first approximation instead of with the uncorrected scale.

By adding the numbers in Tables XXIV. and XXVIII. the quantities entered in Table XXIX. are obtained, which constitute the corrections or the second approximation for the upper points.

Table XXIX.

$\phi\ (\mathrm{U}kr) + \phi'\ (\mathrm{U}kr) = \phi_2\, \mathrm{U}kr$

0	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.
98	2	−3	−2	−1	−5	−2	2	3	3	3
100	0	0	5	−7	−2	−5	0	−1	0	5
102	−7	−4	2	−4	−2	−1	−4	0	10	9
104	−5	0	3	−5	0	−1	0	5	3	3
106	−5	−1	0	4	−6	1	−6	8	−1	6
108	−2	1	−2	−5	1	3	5	−4	3	−6
110	1	−1	−4	2	3	2	2	5	−2	−6
112	−2	3	−1	3	5	2	3	−10	−3	1
114	8	−3	−1	5	4	−1	−3	0	−7	−8
116	4	6	2	5	·6	1	4	−4	−10	−13

The numbers in Table XXIX. are plotted down in fig. 3, Plate II., and the mean of the ordinates of the curves is taken as in the first approximation, and these when added to those of the first mean curve form the second mean curve.

It is, however, necessary below 116° to combine these curves with the corrected initial point curve. It has been shown that if $\phi(i_r)$ be the correction for the r^{th} initial point, $\phi(i_r) = h_r = \mathrm{H}_r - i_r$ plus a constant which, as differences only are required, may for the present be neglected. Now, by taking the mean of the initial and upper point curves at that part of the scale where they overlap, $\phi(i_r)$ is changed into

$$\psi(i_r) = \phi(i_r) + \varpi_r,$$

where ϖ_r is the *difference at that point between the first mean curve and the first initial point curve.*

The analogue of Table XXII. in the second approximation would therefore be drawn up as under:—

Initial points.	I.	II.
$i_1 + \phi(i_1) + \varpi_1$	$u_{1,1} + \phi(u_{1,1})$	&c.
$i_2 + \phi(i_2) + \varpi_2$	$u_{1,2} + \phi(u_{1,2})$	&c.
$i_{10} + \phi(i_{10}) + \varpi_{10}$	$u_{1,10} + \phi(u_{1,10})$	&c.

Hence the correction for the r^{th} initial point (omitting the constant) would be:

$$\frac{1}{10}(u_{1,r} + u_{2,r} + \ldots + u_{10,r}) + \frac{1}{10}\{\phi(u_{1,r}) + \phi(u_{2,r}) + \ldots + \phi(u_{10,r})\}$$
$$- i_r - \phi(i_r) - \varpi_r.$$

But

$$\frac{1}{10}(u_{1,r} + u_{2,r} + \quad + u_{10,r}) = \mathrm{H}_r = \phi(i_r) + i_r,$$

plus a constant which may be neglected, and

$$\frac{1}{10}\{\phi(u_{1,r}) + \phi(u_{2,r}) + \quad + \phi(u_{10,r})\},$$

is equal to the quantity entered in Table XXVI. as h'_r.

$$\text{Hence } \phi'(i_r) = h'_r - \varpi_r.$$

The values of ϖ_r taken out from the first mean and first initial point curves in figs. 2 and 1, Plate II. are entered in Table XXVII. In the next column are the differences between the values of $h'_r - m'$ and ϖ_r.

The additional correction for 116° from the second upper point curves is $-$ ·002. Hence, by adding 6 to the values of $h'_r - m' - \varpi_r$, the ordinates of the second initial point curve are obtained which are entered in the last column of Table XXVII. By taking the mean of these and the upper point curves where they overlap, the following second approximation corrections are obtained in Table XXX.

TABLE XXX.

Corrections of initial points (second approximation) expressed in terms of 0°·001.

98	− 3	108	− 7
100	3	110	− 5
102	8	112	− 4
104	11	114	− 2
106	− 5	116	− 2

In order still further to correct the upper part of the scale, the following method is adopted. The full corrections for the initial and upper points are taken out from the second mean curve and entered in Table XXXI.

If to any mean thread-length, i.e. to the value of v_k obtained in Table XIX., the mean correction for its upper points be added, and that

Table XXXI.

Correction of Lower and Upper Points from Mean Curve II.

0	$\phi_2(i)$	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.	h''	$h''-m''$
98	−297	−45	−23	−49	−42	−32	−14	0	17	24	17	−14·7	−11
100	−222	−23	−27	−45	−29	−19	7	21	24	8	9	− 7·4	− 4
102	−133	−29	−54	−30	− 7	3	26	23	8	17	24	− 1·9	2
104	− 83	−55	−40	−11	12	23	18	8	16	26	21	1·8	5
106	− 40	−38	−28	10	26	21	9	19	27	6	− 2	5·0	8
107	− 23	−28	− 6	26	11	8	23	26	7	−12	−28	2·7	6
110	− 31	− 5	13	15	11	20	22	5	−10	−43	−43	− 1·5	2
112	− 55	+14	26	9	26	26	0	−12	−42	−30	−19	− 0·2	3
114	− 37	+26	12	24	17	4	−23	−44	−33	−15	−20	− 5·2	− 2
116	− 27	+11	11	21	− 3	−14	−44	−28	−16	−29	−38	−12·9	−10
Mean	− 94·8	−17·2	−11·6	−3·0	2·2	4·0	2·4	1·8	−0·2	−4·8	−7·9	$m''=-3·4$	

Table XXXII.

Corrected Mean Lengths of Threads (Second Approximation).

Uncorrected Length	Correction	Corrected Length
7·855	·078	7·933
9·766	·083	9·849
13·398	·092	13·490
15·757	·097	15·854
16·831	·099	16·930
19·310	·097	19·407
20·689	·097	20·786
22 419	·094	22·513
24·593	·090	24·683
25·510	·087	25·597

Table XXXIII.

Errors of Additional Measures, in terms of 0°·001.

0	I.	II.	III.	IV.	V.	VI.	VII.	VIII.
118	−16	−29	− 5	24	39	20	14	27
120	−15	− 2	47	44	30	30	45	—
122	14	29	66	43	37	59	—	—
124	16	40	30	18	38	—	—	—
126	43	47	36	55	—	—	—	—
128	64	46	66	—	—	—	—	—
130	31	41	—	—	—	—	—	—
132	19	39	—	—	—	—	—	—
134	10	—	—	—	—	—	—	—

for its initial points (both taken from Table XXXI.), be subtracted, the corrected thread-length is obtained. These are exhibited in Table XXXII.

The errors of the additional measures (given in Table XXXIII.) are obtained by subtracting the corrected thread-lengths from the uncorrected lengths given in Table XX.

If now the corrections for the lower ends of the additional measures $\phi_2(i_r)$ be taken out from the second mean curve, the corrections for the upper ends can be calculated.

Table XXXIV.

Corrections for Initial and Upper Points of Additional Measures, in terms of 0°·001.

0.	$\phi_2(i)$	I.	II.	III.	IV.	V.	VI.	VII.	VIII.
118	− 4	12	25	1	−28	−43	−24	−18	−31
120	15	30	17	−32	−29	−15	−15	−30	
122	26	12	− 3	−40	−17	−11	−33		
124	10	− 6	−30	−20	− 8	−28			
126	12	−31	−35	−24	−43				
128	27	−37	−19	−39					
130	14	−17	−27						
132	− 6	−25	−45						
134	−36	−46							

The values of $\phi_2\,(i_r)$ are entered in Column I., Table XXXIV., and by subtracting from these the numbers in Table XXXIII., the upper point corrections are obtained.

The corrections given by each thread are plotted down in fig. 4, Plate II.; and the curve shown in fig. 5 is obtained by taking the mean of their ordinates.

It agrees closely with the second mean curve. Where they diverge, as in the neighbourhood of 134° and 140°, the mean is taken and plotted down in fig. 2, Plate II., in the curve drawn thus : —·—·—:

The curve thus finally attained must next (for purposes of comparison) be converted into a standard curve.

The corrections for 100° and 140° are: − 0·223 and − 0·022 respectively.

Hence, in accordance with the formula given in Part I., p. 147, the following quantity must be added to the corrected readings:—

$$0{\cdot}223 - \frac{0{\cdot}201}{40}\left\{x + \phi\,(x) + 0{\cdot}223 - \frac{0{\cdot}201}{40}\,x\right\}.$$

$$\text{Now}\quad \frac{0{\cdot}201}{40}\left\{\phi\,(x) + 0{\cdot}223 - \frac{0{\cdot}201}{40}\,x\right\}$$

only amounts to 0·001 if the quantity inside the brackets = ·2.

The values of $\phi\,(x) + 0{\cdot}223$ are given in Column III. of the following Table XXXV. They exceed ·1 when x is >2. As x increases, however, the quantity $\frac{0{\cdot}201}{40}x$ becomes greater, and at about 125° it reduces the expression below ·1. On the other hand, the last significant figure of the numerator in the fraction $\frac{0{\cdot}201}{40}$ introduces a term $>{\cdot}0005$ when x is >20.

On the whole, therefore, if the expression be written in the form $0{\cdot}223 - {\cdot}005\,x - {\cdot}001$, the last term being only used when x is >2, no error amounting to 0·001 will be made.

TABLE XXXV.

I.	II.	III.	IV.	V.
100	−223	0	0	0
101	−177	46	− 5	41
102	−134	89	− 10	79
103	−106	117	− 16	101
104	− 84	139	− 21	118
105	− 59	164	− 26	138
&c.				
138	− 16	207	−191	16
139	− 17	206	−196	10
140	− 22	201	−201	0
141	− 31	192	−206	− 14

The corrections for the initial points which will be required afterwards are as follows:—

TABLE XXXVI.

100	0	110	141
102	79	112	107
104	118	114	115
106	151	116	115
108	159	—	—

BESSEL'S METHOD.

Further Modifications in the Calculations.

(31) Having thus described Bessel's method as modified by von Oettingen, it is necessary to indicate some points in which it appears to be susceptible of improvement.

The most obvious objection is that the scale is corrected by different methods in different parts, and with varying degrees of accuracy.

In the first approximation, the middle part of the scale is corrected by observations on all the ten threads, the upper part by observations on three, two, and at last on one only. It is true that in the second approximation the additional measures are introduced, but the corrections for the lower ends of these are of unequal value. Thus the correction at 124° is determined from 9 curves, that at 134° is found from 5. The latter must, therefore, be the more uncertain, and this uncertainty will be as it were transmitted to the upper ends of the threads measured at these points in the additional observations.

At the lower end of the scale matters are still more unsatisfactory. In the opinion of von Oettingen (*loc. cit.*, p. 14), the corrections for the initial points are of the same value as those for the upper ends of the threads. If this be so, only four points are corrected between 98° and

105°, while 33 determinations of the corrections of equal value are made between 122° and 129°, without including the additional observations.

Such an arrangement of the experiments is evidently unsatisfactory. It will be hereafter shown that von Oettingen has probably under-estimated the value of the corrections of the principal points, but making all allowance for the much higher value which should probably be assigned to them, there can be no doubt that the correction is either determined unnecessarily often in the middle of the scale, or at too great intervals in the lower part.

It appears, then, that the extremities of the scale are the portions upon the corrections of which least reliance can be placed. This is especially unfortunate. Delicate thermometers are now commonly graduated for a part only of the range between 0° and 100° C. As, therefore, such instruments can have at the most but one fixed point, the temperature value of a scale division must be determined by comparing them at two temperatures with another instrument upon which the other fixed point can be read. If two thermometers do not cover the whole range between the freezing and boiling points, the comparison may have to be made by several intermediate steps. Each instrument in a set of such thermometers is, therefore, constructed so as to overlap those which read above and below it. To avoid the necessity for having too many thermometers, this overlap rarely exceeds one-fourth of the scale and is often less. Hence the errors in the absolute measurements made by a given thermometer will be several times greater than the errors made in the measurement of the temperature-difference necessary to determine the value of the overlap. The extremities of such thermometers should, therefore, be the most carefully corrected, and yet it is here that the method under discussion is weakest.

Objection may also be taken to the method of grafting the initial point correction curve with those portions of the correction curves for the upper points which affect the same part of the scale.

Von Oettingen, referring to an example in which eight threads were used, says (*loc. cit.*, p. 14): 'Für die Curve der arithmetischen Mittel . . . sind ausser den 64 Verbesserungen der 8 mal 8 oberen Fadenenden, noch die enimal 8 Correktionen der unteren Enden hinzugenommen. In der That haben diese Verbesserungen dasselbe Gewicht wie der oberen Enden.'

This view appears open to objection. It is quite true, as von Oettingen adds, that the expressions obtained by him for the corrections of an upper and a lower point both contain the same assumptions, which are only approximately true—viz., that the sum of the errors of any row and of any column are separately $= 0$.

But he determines the error of the topmost initial point (116) from the means of the curves of the upper points. To this, therefore, the full weight, 10 (if 10 threads are used), must be assigned.

In using the formula $\phi(i_9) - \phi(i_{10}) = h_9 - h_{10}$, the only quantity neglected is the difference of the means of the corrections of the upper points in the ninth and tenth rows. Now, since the upper points in these rows extend over nearly the same part of the scale, the difference of these quantities—i.e. $h'_9 - h'_{10}$—must be small. In the example given it amounts to 0°·007. Hence $\phi(i_9)$ must be known with considerable accuracy. The value of $\phi(i_8)$ will be more doubtful, and so on. On the other hand, the weight 10 is perforce assigned to corrections given by the initial point curve at the lower end of the scale, inasmuch as no

others are available. It seems, therefore, unreasonable to entrust the correction entirely to the initial point curve up to the point where the first upper point curve overlaps it, and then suddenly to regard it as of equal value to this, which is itself only one out of ten curves which are used to determine the correction in the centre of the scale.

Experiment fully confirms this view. In no case, either of examples worked out by members of the Committee or of those given by von Oettingen, do the corrections given by the initial point-curve differ on a first approximation from the values they ultimately assume so much as do many of those given by the upper point curves.

(32) In calibrating their thermometers, therefore, Professors Thorpe and Rücker thought it better to weight the initial point curve 10, the upper point curves being weighted 1, to introduce the additional measures in the first approximation, and to determine the initial point of any additional measure with full accuracy before using it to determine the error of its upper point.

For this purpose the calculations were carried on exactly as in the previous method up to and including Table XXIV., and the upper point and initial point curves were drawn. The mean ordinates of the upper point curves were calculated from the highest initial point (116°) up to the point where the first upper point curve ended (123°). The means of the lower parts of the upper point curves and of the initial point curve were then taken, giving the latter the weight 10, and thus the first mean curve was formed from 98° to 123°. It is given in fig. 1, Plate III.

The additional observations were now at once introduced, and the calculations required the gradual building up of five Tables at the same time. The highest point given by Thread I. is at 123°·9; hence the corrections for the initial points and for all the upper points on Thread I. were taken out from the first mean curve and entered in Table XXXVII., in the columns headed φ (i) and I. respectively.

Table XXXVII.

Corrections of Upper and Initial Points from Mean Curve 1, *fig.* 1, *Plate III.*, *expressed in terms of* 0°·001.

0	$\phi(i)$	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.	h'
98	−294	−61	−39	−53	−47	−32	−13	2	19	24	18	−18
100	−225	−38	−34	−51	−25	−18	9	22	25	9	11	− 9
102	−140	−35	−61	−26	− 7	5	26	23	9	17	22	− 3
104	− 94	−61	−44	−10	14	24	18	8	16	24	19	1
106	− 56	−43	−25	11	26	22	11	18	24	7	− 3	5
108	− 36	−24	− 5	26	12	8	22	24	8	−12	−24	4
110	− 37	− 4	15	16	13	19	20	5	−10	−35	−34	1
112	− 62	15	26	11	24	23	− 1	−13	−34	−25	−16	1
114	− 41	26	12	22	15	4	−20	−36	−27	−11	−13	− 3
116	− 24	12	12	19	− 5	−14	−35	−23	−11	−22	−32	−10
—	−101	−21	−14	− 3	2	4	4	3	2	− 2	− 5	$m' = -3$

The mean of the ϕ (i)'s subtracted from the mean of the numbers in Column I. gives the correction on the mean value of Thread I. given in

Table XXXVIII. Hence the corrected value of Thread I. is obtained as in Table XXXVIII.

TABLE XXXVIII.

Corrected Mean Lengths of Threads.

Uncorrected Length from Table XIX.	Correction	Corrected Length L	Uncorrected Length from Table XIX.	Correction	Corrected Length L
7·855	·080	7·935	19·310	·105	19·415
9·766	·087	9·853	20·689	·104	20·793
13·398	·098	13·496	22·420	·103	22·523
15·757	·103	15·860	24·593	·099	24·692
16·831	·105	16·936	25·510	·096	25·606

Subtracting this mean thread-length from the uncorrected lengths given in Table XIX., the errors of the additional measures of Thread I. are found, and entered in Column I., Table XXXIX.

The corrections of the initial points between 116 and 122 being known from the first mean curve, which is complete up to 123, they are entered in Table XL., and by subtracting from these the errors of the additional measures in Table XXXIX., the corrections for the upper points of the first three additional measures of Thread I. are found and entered in Column I., Table XL. The points to which these correspond are given in Column I., Table XXI., and by their aid the correction curve given by Thread I. can be prolonged as in fig. 2, Plate III.

TABLE XXXIX.

Errors of Additional Measures = L − *L, in terms of* 0°·001.

0	I.	II.	III.	IV.	V.	VI.	VII.	VIII.
118	−18	−33	−11	18	33	12	7	17
120	−17	− 6	41	38	24	22	38	
122	12	25	60	37	31	51		
124	14	36	24	12	32			
126	41	43	30	49				
128	62	42	60					
130	29	37						
132	17	35						
134	8							

Using this prolongation, the mean curve can now be prolonged for two or three degrees by means of all the ten curves—viz., nine in fig. 1, Plate II., and one in fig. 2, Plate III.—i.e., it is prolonged far enough to take out, as in Column II., Table XXXVII., all the corrections for the upper points of Thread II. The same process can then be repeated with this thread, and thus gradually all the ten curves, by means of which the first mean curve is constructed, are formed—the initial point of each additional measure being determined, with the full accuracy of which the first approximation is capable.

(33) The second approximation is then carried out in exactly the same way.

Tables XLI. and XLII. are obtained from Table XXXVII., Table XLIII. from Tables XXIV. and XLII. The corrections for the initial

Table XL.

Correction for Initial and Upper Points of Additional Measures, in terms of 0°·001.

0	$\phi(i)$	I.	II.	III.	IV.	V.	VI.	VII.	VIII.
118	−3	15	30	8	−21	−36	−15	−10	−20
120	17	34	23	−24	−21	−7	−5	−21	
122	26	14	1	−34	−11	−5	−25		
124	11	−3	−25	−13	−1	−21			
126	13	−28	−30	−17	−36				
128	25	−37	−17	−35					
130	14	−15	−23						
132	−6	−23	−41						
134	−29	−37							

points are obtained as previously described (p. 187), and entered in Table XLIV.; and the second mean curve is completed as before up to 123°.

Table XLI.

$(v'_k - u'_{kr})$

Derived from Table XXXVII. (*In terms of* 0°·001).

0	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.	$h'_z - m'$	ϖ_z	$h'_r - m' - \varpi_r$
98	40	25	50	49	36	17	1	−17	−26	−23	−15	0	−15
100	17	20	48	27	22	−5	−19	−23	−11	−16	−6	0	−6
102	14	47	23	9	−1	−22	−20	−7	−19	−27	0	0	0
104	40	30	7	−12	−20	−14	−5	−14	−26	−24	4	0	4
106	22	11	−14	−24	−18	−7	−15	−22	−9	−2	8	5	3
108	3	−9	−29	−10	−4	−18	−21	−6	10	19	7	7	0
110	−17	−29	−19	−11	−15	−16	−2	12	33	29	4	4	0
112	−36	−40	−14	−22	−19	5	16	36	23	11	4	5	−1
114	−47	−26	−25	−13	0	24	39	29	9	8	0	3	−3
116	−33	−26	−22	7	18	39	26	13	20	27	−7	0	−7

Table XLII.

$\phi'(\acute{U}_{kr}) = v'_k - u'_{kr} + h'_r - m')$. *In terms of* 0°·001.

	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.
98	25	10	35	34	21	2	−14	−32	−41	−38
100	11	14	42	21	16	−11	−25	−29	−17	−22
102	14	47	23	9	−1	−22	−20	−7	−19	−27
104	44	34	11	−8	−16	−10	−1	−10	−22	−20
106	30	19	−6	−16	−10	1	−7	−14	−1	6
108	10	−2	−22	−3	3	−11	−14	1	17	26
110	−13	−25	−15	−7	−11	−12	2	16	37	33
112	−32	−36	−10	−18	−15	9	20	40	27	15
114	−47	−26	−25	−13	0	24	39	29	9	8
116	−40	−33	−29	0	11	32	19	6	13	20

TABLE XLIII.

$\phi(U_{kr}) + \phi(U_{kr}) = \phi_2(U_{kr})$. *In terms of* 0°·001.

0	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.
98	10	7	0	1	−8	−6	−3	− 1	0	0
100	11	3	10	−11	−5	−6	−2	− 2	−2	0
102	− 5	2	− 2	− 5	−4	−1	−4	− 1	7	6
104	− 1	2	1	− 5	−1	1	0	3	3	1
106	− 3	−5	0	5	−4	1	−6	10	0	5
108	− 8	−2	− 1	− 2	2	5	7	− 2	5	−4
110	− 3	−3	0	1	4	5	4	7	−1	−7
112	− 6	0	− 3	3	6	3	5	− 9	−4	2
114	3	−5	− 2	6	3	1	−3	− 1	−4	−4
116	− 2	−1	0	2	6	−1	1	− 2	−3	−4

TABLE XLIV.

Mean Ordinates from Initial and Upper Point Curves, in terms of 0°·001.

106	5	111	1
107	3	112	0
108	2	113	0
109	1	114	−1
110	1	115	−4
		116	−6

The additional measures are then again introduced. Let L, L and $L + l$, be an uncorrected measure of the length of a thread, and the means of the ten ordinary measures of the same thread correct to a first and second approximation respectively.

Let $\phi(u)$, $\phi(i)$, $\phi_2(u)$ and $\phi_2(i)$ be the corrections for the upper and initial points of the thread, correct to a first and second approximation respectively.

Hence, $$\mathrm{L} + \phi_2(u) - \phi_2(i) = L + l;$$

but $$\phi_2(u) = \phi(u) + \phi'(u), \text{ and } \phi_2(i) = \phi(i) + \phi'(i).$$
$$\therefore\ \phi'(u) = \phi(i) + \phi'(i) + l - \{\mathrm{L} - L + \phi(u)\}.$$

To apply this formula, Table XLV. is found from the second mean curve, exactly as Table XXXVII. was found from the first—i.e. the columns $\phi(i)$ and I. are completed and their means taken. As before, the difference between v_1 and the mean of the $\phi(i)$'s gives the correction for the mean value of Thread I., and thus the corrected length of that thread is found as in Table XLVI. The difference between the corrected lengths in Tables XLVI. and XXXVIII. give the values of l, which are given in the last column of Table XLVI. The values of the corrections for the upper points of the additional threads are then taken out from the first mean curve and entered in Table XLVII.; and these, being added to the corresponding values of L − L in Table XXXVIII., give the values of L − L + $\phi(u)$ entered in Table XLVIII.

Table XLV.

Corrections of Initial and Upper Points from corrected Mean Curve.
In terms of 0°·001.

0	$\phi_2(i)$	I.	II.	III.	IV.	V.	VI.	VII	VIII.	IX.	X.	h''	$h''-m''$
98	−309	−56	−36	−52	−47	−35	−16	−2	16	24	16	−19	−16
100	−229	−35	−34	−51	−30	−22	4	20	25	8	11	−10	−7
102	−138	−34	−60	−31	−9	0	25	23	8	18	26	−3	0
104	−88	−61	−44	−13	11	22	16	9	17	28	21	1	4
106	−51	−42	−30	6	26	21	11	20	28	9	1	5	8
108	−34	−30	−7	26	11	10	25	27	11	−9	−23	4	7
110	−35	−7	11	14	13	21	23	9	−8	−36	−35	1	4
112	−62	12	26	11	28	27	3	−11	−35	−23	−14	2	5
114	−42	26	10	26	19	8	−19	−37	−26	−11	−12	−2	1
116	−30	11	13	22	0	−12	−36	−22	−11	−21	−32	−9	−6
	−102	−22	−15	−4	2	4	4	4	3	−1	−4	−3	

Table XLVI.

Corrected Mean Lengths of Threads (second approximation).

Uncorrected length	Correction	Corrected length	Difference between 2nd and 1st approxs. =
7·855	·080	7·935	·000
9·766	·087	9·853	·000
13·398	·098	13·496	·000
15·757	·104	15·861	·001
16·831	·106	16·937	·001
19·310	·106	19·416	·001
20·689	·106	20·795	·002
22·420	·105	22·525	·002
24·593	·101	24·694	·002
25·510	·098	25·608	·002

Table XLVII.

(ϕ (u)).

Corrections for Upper Points of Additional Measures from 1*st Mean Curve fig.* 1, *Plate* III. *In terms of* 0°·001.

0	I.	II.	III.	IV.	V.	VI.	VII.	VIII.
118	13	24	−2	−28	−36	−17	−11	−19
120	25	15	−21	−33	−21	−13	−23	
122	14	−5	−34	−13	−11	−31		
124	−6	−28	−16	−14	−24			
126	−29	−33	−12	−37				
128	−32	−13	−32					
130	−13	−14						
132	−14	−36						
134	−37							

The second mean curve being completed up to 123° enables the first three values of ϕ (i) + ϕ' (i) to be taken out in Table XLIX.; and by

means of Table XLVIII., and the values of l, the corrections for the upper points of the first three additional measures of Thread I. are found. By this means the curve given by Thread I. is prolonged, and the operation of completing the second mean curve is carried out in a manner similar to that adopted in the first approximation.

TABLE XLVIII.

$L - \mathit{L} + \phi(u)$. In terms of $0^\circ{\cdot}001$.

0	I.	II.	III.	IV.	V.	VI.	VII.	VIII.
118	−5	−9	−13	−10	−3	−5	−4	−2
120	8	9	20	5	3	9	15	
122	26	20	26	24	20	20		
124	8	8	8	−2	8			
126	12	10	18	12				
128	30	29	28					
130	16	23						
132	3	−1						
134	−29							

TABLE XLIX.

Corrections for Upper Points of Additional Threads plotted down in Curves in fig. 4, Plate III.

$\phi(i) + \phi'(i) + l - (L - \mathit{L} + \phi(u))$. In terms of $0^\circ{\cdot}001$.

0	$\phi(i) + \phi'(i)$	I.	II.	III.	IV.	V.	VI.	VII.	VIII.
		$l=0$	0	0	1	1	1	2	2
118	−6	−1	3	7	5	−2	0	0	−2
120	13	5	4	−7	9	11	5	0	
122	26	0	6	0	3	7	7		
124	9	1	1	1	12	2			
126	14	2	4	−4	3				
128	29	−1	0	1					
130	17	1	−6						
132	−3	−6	−2						
134	−30	−1							

The curve must now be made to pass through the standard points.

This operation is performed as in the previous example, the formula in this case being

$$0{\cdot}230 - \frac{0{\cdot}215}{40}\left\{x + \phi(x) + 0{\cdot}230 - \frac{0{\cdot}215}{40}\,x\right\}.$$

It is unnecessary to give details. The correction for the initial points are:—

TABLE L.

100	0	110	140
102	81	112	102
104	119	114	111
106	146	116	113
108	151	—	—

The curve is exhibited in fig. 3, Plate I.

(34) On comparing the two methods a glance at the first and second approximation curves in fig. 2, Plate II., and fig. 1, Plate III., establishes a *primâ-facie* case in favour of that adopted by Professors Thorpe and Rücker. In von Oettingen's method there is a considerable difference between the two curves at the part affected by the additional measures, and also at the points where the initial and upper point curves overlap. In the curve obtained by the second method, the agreement is perfect at the top of the scale, and very much better in the neighbourhood of the overlap. The greatest difference occurs at the points which the previous discussion indicates as the weakest—namely, the lower initial points. The much closer agreement between the values of $h'_r - m'$, and of $h'_r - m' - \varpi_r$, exhibited in fig. 3, Plate III., than between those in fig. 3, Plate II., is also a point in favour of attributing the weight 10 to the initial point curve.

It is, however, possible to submit the differences in the neighbourhood of the overlap to a closer investigation. The values of h'' in Tables XXXI. and XLV. enable the correction of the initial points to be carried a stage further. It follows from the investigation of the correction of the initial points already given (p. 187) that, just as in the first approximation, the process of combining the initial and upper point curves changes $\phi\ (i_r)$ into $\phi\ (i_r) + \varpi_r$; so, in the second approximation, it will change $\phi'\ (i_r)$ into $\phi'\ (i_r) + \varpi'_r$. Hence, if $\psi'\ (i_r)$ is the difference between the second and first mean curves at the r^{th} initial point,

$$\psi'\ (i_r) = \phi'\ (i_r) + \varpi'_r.$$

By a method similar to that by which the correction was obtained in the second approximation, the third correction is now found to be

$$\phi''\ (i_r) = \mathrm{H}_r - i_r + h'_r + \tfrac{1}{10}\ \{\phi'\ (u_{1,r}) + \phi'\ (u_{2,r}) + \&c.\} \\ - \phi\ (i_r) - \phi'\ (i_r) - \varpi_r - \varpi'_r.$$

Now, since in Tables XXXI. and XLV. the whole correction is taken out—i.e. $\phi_2\ (u)$—and not merely the difference between the first and second approximations—i.e. $\phi'\ (u)$.

$$h'_r + \tfrac{1}{10}\ \{\phi'\ (u_{1,r}) + \phi'\ (u_{2,r}) + \&c.\} = h''_r;$$

and since $\qquad \phi\ (i_r) = \mathrm{H}_r - i_r,$

and $\qquad \varpi'_r = \psi'\ (i_r) - \phi'\ (i_r),$

it follows that $\qquad \phi''\ (i_r) = h''_r - \varpi_r - \psi'\ (i_r).$

As $\varpi_r + \psi'\ (i_r)$ is the difference between the second mean curve and the first initial point curve, this expression is exactly comparable with that obtained in the first approximation.

In Table LI. the values of $\phi''\ (i_r)$ are calculated according to both methods.

The values of $\phi''\ (i_r)$ require the addition or subtraction of a constant in order to bring the curves given by them into agreement at one point with that obtained from the second mean curves. The corrected curves could then be made to pass through the standard points.

As, however, the values of $\phi''\ (i_r)$ are nearly the same at 100° and 116°, and as the resulting corrections are very small, no appreciable error will be committed if they are considered as applied directly to the standard curves. A third approximation to the corrections of the initial

points may therefore be obtained, under conditions such that the two methods may be compared by adding to the values of $\phi''(i_r)$ the corrections for the initial points taken from the standard curves, together with the constants (K) necessary to make the corrections at 100° zero.

This operation is performed in Table LII.

Table LI.

Expressed in terms of 0°·001.

Von Oettingen.

	h''_r, from Table XXXI.	ϖ_r, from Table XXVII.	$\psi'(i_r)$, from Curves fig. 2, Plate II.	$\phi''(i_r)$
98	−15	0	− 4	−11
100	− 7	0	2	− 9
102	− 2	0	8	−10
104	2	0	10	− 8
106	5	25	− 7	−13
108	3	28	− 8	−17
110	− 2	14	− 5	−11
112	0	18	− 5	−13
114	− 5	10	− 3	−12
116	−13	0	− 3	−10

Thorpe and Rücker.

	h''_r, from Table XLV.	ϖ_r. from Table XLI.	$\psi'(i_r)$, from Curves fig. 1, Plate III.	$\phi''(i_r)$
98	−19	0	−15	−4
100	−10	0	− 5	−5
102	− 3	0	2	−5
104	1	0	5	−4
106	5	5	4	−4
108	4	7	2	−5
110	1	4	1	−4
112	2	5	0	−3
114	− 2	3	− 1	−4
116	− 9	0	− 6	−3

Table LII.

	Von Oettingen		Thorpe and Rücker	
	Second approxm. from Table XXXVI.	Third approxm. $K = 9$	Second approxm. from Table L.	Third approxm. $K = 5$
100	0	0	0	0
102	79	78	81	81
104	118	119	119	120
106	151	147	146	147
108	159	151	151	151
110	41	139	140	141
112	107	103	102	104
114	115	112	111	112
116	115	114	113	115

In Table LII., the last three columns are in virtual agreement, while the second differs from all of them in that the correction in the neighbourhood of 108° is too great. This is exactly what would occur on the assumption that von Oettingen had not given sufficient weight to the initial point curve.

The maximum error would occur in the neighbourhood of the point where the initial and upper point-curves first overlap, as there, owing to the small number of the upper point-curves, the errors introduced by them would be most important. The nature of the error would be such that the correction curves would be deflected too far in the direction of the upper point-curves, and finally it would be eliminated by a sufficient number of approximations.

All these conditions are fulfilled. The overlap begins at 106. At that point there is a sudden increase in the difference between the first and second approximations, which is a maximum at 108°. The upper point-curves lie above the initial point-curve; and the second approximation, given by von Oettingen's method, lies above the third. The third approximation agrees very closely with the second and third approximations obtained by Professors Thorpe and Rücker's method, which are themselves in virtual agreement.

The upper part of von Oettingen's curve is, however, for the most part above that obtained by the other method, and this error is no doubt due to the less rapid approximation obtained by ranking the initial point-curve as equal to one of the upper point curves only.

On these grounds, therefore, the curve calculated, on the supposition that the initial point-curve is equivalent in value to ten of the upper point-curves, will be taken as the standard.

(35) Only one other point with regard to Bessel's method requires investigation, viz. the error introduced by the measurement of the thread, not at, but near, the principal points. Let the true lengths of the divisions on which the upper and lower ends of a thread lay be $1 + d_u$ and $1 + d_i$. Let y be the fraction of the division in which the lower end lay by which that end was distant from the principal point. Had the thread been pushed back through this distance its length would have been increased by $y(d_u - d_i)$.

All the numbers in Tables XX. and XXI. must therefore be increased by this amount. Assuming y to have a mean value $\bar{y}$ throughout, and inserting this correction in the formula on p. 182, it is easily proved that the added correction of U_{kr} is

$$\bar{y}\left\{\frac{1}{10}\Sigma_r d_u - d_u - \frac{1}{10}\Sigma_k d_u - \frac{1}{10^2}\Sigma_k \Sigma_r d_u\right\},$$

where $\Sigma_r d_u$ and $\Sigma_k d_u$, are the sums of all the values of d_u in the r^{th} row, and the k^{th} column respectively, and $\Sigma_k \Sigma_r d_u$, is the sum of all the values of d_u.

The correction for the r^{th} initial point is increased by $\bar{y}\{\Sigma_r d_u - d_i\}$.

On taking out the values of d_u and d_i from the curves in fig. 1, Plate III., it is found that the largest correction for any upper point is $0{\cdot}002\bar{y}$, and for any initial point $0{\cdot}003\bar{y}$, and since the value of $\bar{y}$ is about 0·3, the error introduced cannot exceed 0°·001. The mean curves may, therefore, as far as this error is concerned, be taken as correct to 0°·001, and it has therefore been neglected.

Effect of Errors in Measurement of Threads.

(36) The errors introduced in a correction-method depend partly upon the magnitude of the false assumptions made in the method itself, partly upon errors in the measurement of thread.

It has been shown that the former may be obviated to a great extent by approximation or transference; it remains to investigate the latter. It has been thought better to treat of this subject by itself in order to avoid the complication which it introduces into the discussion of the various methods. It is proposed here to investigate the probable errors of the corrections of the principal points in terms of the errors in the thread-measurements. The probable error of a thread-measurement will be considered the same in all cases and taken $= e$. It must, however, be remembered that, in all probability, for reasons already given, long threads are less accurately measured than short.

Gay-Lussac's Method.

The equations (1) (p. 164) show that in the case of Gay-Lussac's method the correction for the r^{th} principal point is

$$\phi(i_r) = r\text{T} - \Sigma_1{}^r t_x = \frac{r}{n} \Sigma_1^n t_x - \Sigma_1{}^r t_x = \frac{r}{n} \Sigma_{r+1}^n t_x - \frac{n-r}{n} \Sigma_1{}^r t_x.$$

Hence if E_r be the probable error of the correction at this point, since all the t's are independent measures

$$\text{E}_r{}^2 = \frac{r^2}{n^2}(n-r)e^2 + \frac{(n-r)^2}{n^2} re^2 = \frac{r(n-r)}{n} e^2.$$

Hence if $n = 10$ the squares of the probable errors at the first, second, &c., points are proportional to $\frac{9}{10}, \frac{16}{10}$, &c.

These numbers are plotted down and give the curve indicated in the figure on p. 158.

Rudberg's Method.

It will be sufficient to consider the case of division into six parts.

The above formulæ give at once

$$\text{E}_3{}^2 = \frac{e^2}{2}, \quad \text{E}_2{}^2 = \text{E}_4{}^2 = \frac{2}{3} e^2.$$

Since the shorter thread is found as the mean of three independent measures its (probable error)$^2 = \frac{e^2}{3}$, and since this thread is measured independently of $\phi(3)$, and $\phi(1)$ is found from the equation

$$-\phi(1) = \text{T} - t_1 - \phi(3),$$

where all the quantities on the right are independent

$$(p.e.\,\phi(1))^2 = \frac{e^2}{3} + e^2 + \frac{e^2}{2} = 1{\cdot}83\, e^2.$$

A curve is drawn through the points thus obtained in the figure on p. 158.

HÄLLSTRÖM'S METHOD.

In the case of Hällström's method the relation between the corrections and the thread-lengths are more complex. They may, however, be obtained as follows. In Table LIII. the first column gives the various δ's, the other columns the coefficients with which τ's and σ's occur in the expressions for them.

Thus, for instance, $\delta\,(2) = \delta\,(1) + \sigma_3 - \sigma_4 - \tau_3 + \tau_4$, and so on. These are obtained from the formulæ given above (p. 170), and from them $10\delta_1$ is found. Using the value thus obtained, and remembering that $\phi\,(n) = \delta\,(1) + \delta\,(2) + \ldots\ldots + \delta\,(n)$, the values of the ϕ's are found in Table LIV. These have been checked by comparison with Table XIV.

TABLE LIII.

Probable errors.

I.	δ (1)	σ_3	σ_4	τ_2	τ_3	τ_4	τ_5	τ_6	τ_7	τ_8	τ_9	τ_{10}
δ (1)	1											
δ (2)	1	1	−1		−1	1						
δ (3)	1			1	−1							
δ (4)	1	1	−1									
δ (5)	1			1	−1	1	−1					
δ (6)	1	1	−1				1	−1				
δ (7)	1			1	−1	1	−1	1	−1			
δ (8)	1	1	−1				1	−1	1	−1		
δ (9)	1			1	−1	1	−1	1	−1	1	−1	
δ (10)	1	1	−1				1	−1	1	−1	1	−1
$\therefore -10\,\delta(1)$	=	5	−5	4	−5	4		−1		−1		−1

TABLE LIV.

Probable Errors.

I.	σ_3	σ_4	τ_2	τ_3	τ_4	τ_5	τ_6	τ_7	τ_8	τ_9	τ_{10}	Sum of Squares of Coefficients
ϕ (1)	−·5	·5	−·4	·5	−·4		·1		·1		·1	1·10
ϕ (2)			−·8		·2		·2		·2		·2	0·80
ϕ (3)	−·5	·5	−·2	−·5	−·2		·3		·3		·3	1·10
ϕ (4)			−·6		−·6		·4		·4		·4	1·20
ϕ (5)	−·5	·5		−·5		−1	·5		·5		·5	2·50
ϕ (6)			−·4		−·4		−·4		·6		·6	1·20
ϕ (7)	−·5	·5	·2	−·5	·2	−1	·7	−1	·7		·7	4·30
ϕ (8)			−·2		−·2		−·2		−·2		·8	0·80
ϕ (9)	−·5	·5	·4	−·5	·4	−1	·9	−1	·9	−1	·9	6·50
ϕ (10)	0	0	0	0	0	0	0	0	0	0	0	0

Since now each of the σ's and τ's is an independent measure, it is evident that the square of the probable error of the correction of a principal point = square of probable error of a measurement × the sum of the squares of the coefficients in Table LIV., and is therefore proportional to the number given in the last column of that Table.

A curve is, as usual, drawn in the figure on p. 158. If an hypothetical τ_1 is introduced, the correction may be expressed by the following formulæ.

For the odd points,

$$0{\cdot}5\,(\sigma_4 - \sigma_3) - 0{\cdot}5\,(\tau_2 - \tau_3 + \tau_4) + \tau_1$$
$$+ \frac{n}{10}\left\{\tau_2 + \tau_4 + \tau_6 + \ldots\ldots + \tau_{10}\right\}$$
$$- \{\tau_1 + \tau_3 + \ldots\ldots + \tau_n\},$$

and for the even points,

$$\frac{n}{10}\left\{\tau_2 + \tau_4 + \ldots\ldots + \tau_{10}\right\} - \left\{\tau_2 + \tau_4 + \ldots\ldots + \tau_n\right\},$$

where in each case n is the number of the principal point.

Thiesen's Method.

In the case of Thiesen's method the relation between the corrections and the measures is simpler. Suppose the observations complete—i.e. no threads to be wanting.

Referring to the table on page 172, it is evident that the correction for the r^{th} principal point is the sum of all the columns up to and including the r^{th} divided by 10. But the figures in any rectangle of which the 0's form the diagonal cancel one another. Thus the correction for any point is one-tenth of the sum of the figures in all the columns up to the r^{th} with the rectangle in question cut off.

For instance, if in Table XVI. (p. 174), the blank space be filled up with the correct number afterwards found, the correction for i_4 is one-tenth the sum of the figures.

102	15	− 68	− 12
138	60	− 22	35
127	·37	− 51	10
178	77	8	57
177	81	7	·58
131	49	− 39	18

All the numbers in any diagonal such as that through which the line is drawn are obtained from the same thread. They are the differences of successive thread-lengths, and therefore their sum depends only on the first and last. In other words, the number of independent measures used in finding the corrections is twice the number of the diagonals, i.e. it is in all cases 18.

Hence (probable error of correction)$^2 = \frac{18}{10^2}\,e^2 = {\cdot}18\,e^2$.

The curve is drawn in the figure on p. 158.

Mârek's Method.

Mârek gives the formulæ for finding the probable error of a correction. When, as is the case worked out, the tube is divided into five parts, the $(p.\,e\text{'s})^2$ are

$$0{\cdot}\quad 0{\cdot}29\,e^2 \quad 0{\cdot}28\,e^2 \quad 0{\cdot}2{\cdot}8\,e^2 \quad {\cdot}0{\cdot}29\,e^2 \quad 0$$

These are, of course, not comparable with the others above obtained, as the subdivision of the tube is different.

If the tube is divided into five parts by Thiesen's method the $(p.\ e)^2 = 0{\cdot}32\, e^2$.

Bessel's Method.

The above method is not strictly applicable to Bessel's corrections, but it may be approximately applied as follows :—

Each value of h_r depends on 10 independent measurements. Hence

$$(p.\ e.\ h_r)^2 = \frac{e^2}{10}, \text{ \&c.}$$

Each value of $\phi\ (\mathrm{U}_{kr})$ depends on 100 measures.

Ten of these are introduced with the coefficient $0{\cdot}1$ in v_k, ten (of which one is common to this and last group) with the coefficient $0{\cdot}1$ in h_r, and 100 with the coefficient $-0{\cdot}01$ in the m. One, viz., u_{kr} itself, appears again with the coefficient -1. Hence 81 will have the coefficient $-0{\cdot}01$, 18 will have the coefficient $0{\cdot}09$, and 1 the coefficient $-1 + 0{\cdot}2 - 0{\cdot}01 = -{\cdot}81$. Hence the probable error of a single thread-correction is :—

$$\{81 \times 0{\cdot}0001 + 18 \times 0{\cdot}0081 + ({\cdot}81)^2\}\, e^2 = {\cdot}81\, e^2,$$

a result which strongly confirms the view expressed above as to the relative values of the initial point and other corrections.

Let it next be supposed that all the corrections in the diagonal which passes from the lower left to the upper right-hand corner of Table XIX. (p. 180), refer to the same point.

Hence the final correction will be the mean of the ten. These are not independent. Each number in the Table will occur ten times.

Ten, viz., the numbers in the diagonal, will have the coefficient $-0{\cdot}81$ once, and $-0{\cdot}01$ nine times. Their coefficients in the mean will therefore be $-0{\cdot}09$. The remaining ninety will have the coefficient $0{\cdot}09$ twice, and $-0{\cdot}01$ eight times. Their coefficients in the mean will therefore be

$$\frac{1}{10}\left\{0{\cdot}18 - 0{\cdot}08\right\} = 0{\cdot}01$$

Hence the probable error of the correction will be e^2, multiplied by

$$10 \times (0{\cdot}09)^2 + 90 \times (0{\cdot}01)^2 = 0{\cdot}081 + 0{\cdot}009 = 0{\cdot}09.$$

For comparison with the other methods referred to, it would be better to take Bessel's method with five principal points 4° apart. The probable errors of an initial point, and a mean upper point, would then be $0{\cdot}2\, e^2$ and ${\cdot}15\, e^2$, respectively.

Second Report of the Committee, consisting of Sir A. C. Ramsay, Mr. Thomas Gray, *and* Professor John Milne (*Secretary*), *appointed for the purpose of investigating the Earthquake Phenomena of Japan. Drawn up by the Secretary.*

The seismological work which I have been engaged upon since the British Association, in 1881, generously placed in my hands a grant of 25*l.* as an assistance towards the investigation of the earthquake phenomena of Japan, has been partly the continuation of experiments and observations on which I was previously engaged, and partly an endeavour to carry out experiments which are more or less new.

The results of a portion of this work have already been published in the 'Transactions of the Seismological Society of Japan.' The greater portion, however, of the observations which have been made are still in a rough form, and considerable time and labour will have to be expended upon them before they are ready for publication. The results to which many of these observations lead are, however, sufficiently well defined to be described in general terms, and this I propose to do in the following brief report. The order in which the various investigations are referred to is as nearly as possible the same as that which was followed in my first report to this Association. They are as follows:—

I. *Determination of the areas from which the shakings so often felt in Tokio and Yokohama emanate.*

In my first report it was stated that the origins of three earthquakes had been located near to or in the Bay of Yedo, at no great distance from Yokohama. Owing to the fact that there was often a confusion of normal and transverse vibrations, or to the fact that even if the ground moved backward and forward in a definite direction this did not of necessity correspond to the direction of a line connecting the point of observation and the origin, the origins of many other earthquakes which had been felt had not been determined.

During the last year, in consequence of my having established at various places a number of instruments which give graphical records of all the prominent vibrations of an earthquake, instead of simply indicating the extent and direction of the maximum disturbance, I have been enabled to determine approximately the origins of a considerable number of disturbances. The instrument here referred to I call a pendulum seismograph. It is described in Vol. IV. of the 'Transactions of the Seismological Society.'

These instruments have been distributed as follows:—

1.	With F. Ringer, Esq.,	at Nagasaki,	550	geo. miles	W.S.W.	from Tokio.
2.	" St. John Browne, Esq.,	" Kobe,	240	"	W. by S.	"
3.	" A. Owston, Esq.,	" Yokohama,	15	"	S.W. by S.	"
4.	" W. H. Talbot, Esq.,	" "	"	"	"	"
5.	" A Japanese gentleman,	" Chiba,	17	"	E. by S.	"
6.	" " "	" Kisaradzu,	15	"	S.E. by S.	"
7.	" " "	" Kamaishi,	120	"	N.N.E.	"
8.	At my own house,	" Hakodate,	375	"	N. by E.	"
9.	" F. Fukushi, Esq.,	" Saporo	450	"	N. by E.	"
10.	— — —	" Tokio.				

Examples of the records obtained from these instruments, which records are written on plates of smoked glass that are subsequently varnished and photographed, are given with the description of the instrument. The greater number of earthquakes which have been recorded in Tokio have also been recorded in Yokohama, Chiba, and Kisaradzu. Now and then the same earthquake has also been recorded in Kamaishi, and now and then even in Hakodate and Saporo. In no instance during my seven years' residence in Japan have earthquakes, even when they have originated so near to Yokohama as to destroy chimneys and to completely unroof houses, been propagated so far south as Kobe. So far as ordinary earthquakes are concerned Kobe belongs to a special seismic area. Nagasaki in a similar manner is independent of all the other districts where seismographs have been placed. The reason why an ordinary earthquake in North-Eastern Japan is unable to spread far beyond Yokohama towards the south-west apparently depends upon the fact that in going southwards it is intercepted by many high and broad tracts of mountainous country. For a similar reason these same earthquakes are unable to cross the central backbone of the island, and so disturb the inhabitants upon the eastern shores. These facts have been illustrated in a very remarkable manner during the last year by an analysis of some hundreds of communications which I have received from various parts of North Japan.

These communications were obtained by sending to the Government offices at all the important towns within a radius of from 60 to 100 miles of Yedo bundles of post-cards, with a request that every week one of these cards should be returned with a statement of the earthquakes which had been felt. The result obtained by the examination of these communications showed that a great number of earthquakes came from the north-east, and hardly ever passed the ranges of mountains to the west and south-west. Subsequently the boundary of the post-card area was extended farther to the north, and the result which was obtained showed that many earthquakes came from the sea on the east. The general results obtained by this system of investigation are exhibited in a seismological atlas which is being prepared for North Japan, in which the area shaken by every shock has been tinted, the dark tints indicating where the shock was most severely felt, or where there were a number of shocks at short intervals corresponding to the single shock felt at more distant localities. The information to be derived from this series of maps is—

1st. An approximate origin for many of the shocks, which is of great value as a check upon the records of instruments and an assistance to their interpretation.

2nd. In North-Eastern Japan there appear to be several seismic centres, and from these centres ordinary disturbances only radiate into surrounding districts, the boundaries of which are sharply defined by certain ranges of mountains.

3rd. The greater number of seismic centres appear to be beneath the ocean.

4th. In the case of heavy shocks, and shocks which have originated some distance out at sea, the disturbance may be felt over the whole or a great portion of North-Eastern Japan, from Saporo and even Nemuro in the north to Yokohama in the south.

5th. Although disturbances may be felt for several hundreds of miles

along the eastern shores of Japan, it is seldom that they cross the mountains to the north-western coast, which is singularly free from earthquakes.

One inference to be drawn from the above observations is that the disturbance, as felt upon the land, is to a great extent superficial, and on reaching the mountains is either destroyed by reflections and refractions, or else absorbed by their mass.

In the case of earthquakes where there were prominent vibrations having a definite direction, a prolongation of lines parallel to these directions through the observation stations has given intersections corresponding with the locality in which we should seek for the origin of the disturbance from the records of the post-cards. When prominent movements in two or more directions had been recorded, the one which had to be taken to represent the normal motion was indicated by the approximate origin shown by the post-cards.

These determinations were further checked by time observations, usually made in Yokohama, Tokio, and Chiba. Sometimes they were also made in Saporo and Hakodate. Assuming these time observations to have been correct, and the velocity of an earthquake to be constant, it is theoretically possible by several methods to determine the origin of a disturbance. Although these methods fail in practice, chiefly owing to the fact, which I will speak of presently, that the assumed velocity is not constant, the observations lead to very sure and practical deductions as to the direction in which we are to look for the origin of a shock.

II. *Velocity of Propagation of an Earthquake Wave.*

The observations which I have been enabled to make upon the velocity with which earthquake motion is propagated are dependent upon the accuracy of time observations made at the localities just mentioned. In Tokio and Yokohama the observations were usually made automatically, by means of an instrument (which I have described in Vol. IV. of the 'Transactions of the Seismological Society of Japan,' under the name of a 'Time Taker'), which gives a record of the time of a disturbance without stopping or retarding the clock from which it was taken. At Chiba and Kumagai the records were taken by telegraph operators by means of watches which I provided for them. At the remaining stations the observations were made similarly. All watches and clocks were from time to time compared with a telegraphic signal sent daily from the Meteorological Department in Tokio throughout Japan. The only exceptions were Hakodate and Saporo, where the observations were made at observatories well provided with the necessary means of obtaining accurate local time.

The conclusions which these observations lead me to draw are—

1. Different earthquakes, although they may travel across the same district, do so with different velocities, varying between several hundreds and several thousands of feet per second.

2. The same disturbance is propagated with a decreasing velocity, travelling very much more quickly across districts which are near to the origin than across districts which are far removed.

3. The greater the initial force producing a disturbance the greater the velocity of propagation.

As examples of the observations which have led to these deductions I quote the following:—

1. The earthquake of October 25, 1881.

The origin of this was about 41° N. lat. and 144° 15′ E. long. From

the Hakodate homoseist this shock travelled at the rate of about 10,219 feet per second to reach Tokio. Between Tokio and Yokohama the rate of propagation appears to have been about 4,500 feet per second.

2. The earthquake of February 6, and two disturbances on March 1, 1881.

These disturbances, like that of October 25, appear to have travelled in a straight line through Tokio and Yokohama. Their velocities of propagation were respectively about 3,900, 1,900, and 1,400 feet per second.

3. The earthquake of February 16, 1881.

This shock appears to have originated in Yedo Bay, about eight miles east of Yokohama. From the Yokohama homoseist the velocity with which the shock travelled on to Tokio was about 2,454 feet per second.

4. The earthquake of March 11, 1881.

This disturbance originated at a place about nineteen miles S.S.W. from Chiba. The shock was a severe one. From the Tokio homoseist it appears to have travelled at the rate of 2,200 feet per second on to Yokohama.

No doubt, notwithstanding the care which has been taken to have the time observations correctly recorded, it is possible that there may be errors due, for instance, to observers or instruments at the different stations making their records at different portions of the disturbance. Also there may be differences in the calculated velocities due to differences in the topographical and geological nature of the districts traversed by the disturbance.

Although causes such as these may lead to a want of accuracy in the calculations which are here presented, I still regard the results of these calculations as indicating general laws. This view appears to be confirmed by the analysis of a table of earthquake velocities which I have compiled from the writings of various earthquake investigators, and also from the result of experiments on artificially produced disturbances yet to be referred to.

III. *The Nature of Earthquake Motion.*

In my first report to this Association I stated, 1st, that although the upper portions of buildings may at the time of an earthquake move through a considerable distance, the actual motion of the ground does not usually exceed a few millimetres, and is often under one millimetre; 2nd, the backward and forward motions of the ground are very irregular, both as regards period and amplitude; 3rd, that there are seldom more than two or three vibrations per second; and 4th, that the motion often takes place in more than one direction.

To these observations, which have received further confirmation from records of earthquakes taken during the past year, I may add that in certain earthquakes where there are one or more prominent vibrations or what might be called shocks—

1st. That the motion of the ground *inwards* towards the origin of the disturbance is usually much greater than the motion outwards.

2nd. That the velocity, and consequently the acceleration of an earth particle for the inward motion, is usually very much greater than for the outward motion.

In certain instances these two characters—which are of great importance, not only as indicators of the side from which the disturbance came, but also as indicators of the nature of the cause of the disturbance—I have sometimes observed, not simply in one or two vibrations of a disturbance, but in nearly all the vibrations which were sufficiently well defined to be analysed.

Further, it may be added that certain semi-vibrations have been described by the pointer of the seismograph moving across a moving record receiver in the direction of its motion, which have the anomalous appearance of having been described in less than no time.

From these observations it would appear that it is hardly safe for us to regard the backward and forward motion of the earth as simple harmonic motions, and maximum velocities and accelerations calculated upon such an assumption may possibly lead to false results.

IV. *An endeavour to find out the relative extent and variation in direction of the motion of an earthquake at neighbouring points in a given area, the contour and geological structure of which is irregular.*

To work out this problem seven similar seismometers were distributed on the hills and in the valleys near my house. The chief difficulty which had to be overcome in this investigation was to obtain a type of seismometer which, whilst magnifying the actual motion of the ground, was sufficiently simple to allow of a number being employed, and which, when under the same conditions, would give the same result. The results of experiments to find such an instrument are given in Vol. III. of the 'Transactions of the Seismological Society.' The seismometers which were chosen consisted of heavy pendulums suspended in cases to shield them from currents of air. Against the bobs of these pendulums, in grooves at right angles to each other, slips of wood were placed. At the time of an earthquake these, being pushed against the pendulum by the motion of the stands on which they rested, caused pointers which were attached to them by one thread of a bifilar suspension to swing round and give a magnified representation of the motion which had taken place.

The so-called hills surrounding the plain of Tokio are irregular, flat-topped spurs, jutting out from an elevated plateau about 100 feet high into the flat plain on which a great portion of the city of Tokio is situated. The area over which the seismometers were distributed had a radius of about a quarter of a mile. Two of the seismometers were placed on the top of the spurs, two were placed near together on the side of a spur, whilst three were placed at different points on the plain.

The results obtained from the records of fourteen small earthquakes are :—

1st. That the maximum amplitude of motion and the direction of motion at all the stations were different.

2nd. The greatest motion was experienced upon the flat ground, and the least upon the hills and their flanks.

These results have been confirmed by observations made with other instruments. For instance, one of Professor Ewing's bracket seismographs at the University, situated on the flat ground of Tokio, usually records a much larger amplitude of motion than seismographs constructed on similar principles placed at my own house, situated on a small plateau half-way up the side of a hill about a mile distant from the University. Also the duration of a disturbance is longer on the low ground than it is upon the high ground. As an example, the earthquake of March 11, 1882, may be quoted. At the University this disturbance lasted about $4\frac{1}{2}$ minutes, the maximum amplitude of motion being 8 millimetres; at my house the motion could only be traced upon the moving plate on which it was recorded for a period of about $1\frac{1}{2}$ minute, and the maximum amplitude was about 3 millimetres. That there is less disturbance upon the hills than in the plain at Tokio is a fact that has long been recognised by the

Japanese. It was especially remarked at the time of the destructive earthquake of 1854.

In Yokohama, sixteen miles to the S.E., where the high and low ground has almost exactly the same topographical character as at Tokio, the rule appears to be reversed. This was clearly evident in February 1880, when the shattering of chimneys, unroofing of houses, and destruction generally was almost wholly confined to the high ground. In Hakodate the rule appears to be like that for Tokio—namely, that the greatest disturbance is felt upon the low ground.

In consequence of the great difference in motion observed in places which are adjacent to each other, I have hitherto been unable to make any satisfactory determination of the manner in which an earthquake dies out as it radiates from its epicentrum, although on many occasions I have obtained a number of diagrams for the same earthquake from distant stations.

V. *Experiments on artificially produced Earthquakes.*

In 1881, in conjunction with Mr. Thomas Gray, I made experiments upon a series of artificial earthquakes produced by allowing a heavy iron ball to fall from various heights up to 35 feet.

During the past year I continued these experiments on a larger and more satisfactory scale, the disturbances being produced by charges of dynamite exploded in bore-holes usually about 10 feet deep. In the first two sets of experiments the vibrations resulting from the explosions were simultaneously recorded upon moving glass plates at three stations.

In consequence of the great increase in the intensity of the initial disturbance as compared with that obtained from the falling ball, the resulting diagrams showing the backward and forward motions of the ground were much larger, and, therefore, better fitted for analysis than those which had been obtained previously. It also became possible to place the observation stations at greater distances apart, and thus errors in the calculation of velocity arising from inaccuracy in time observations were considerably reduced.

The results obtained were a confirmation of results which had been previously obtained. They were, briefly—

1. A graphic separation of normal and transverse vibrations.

2. A determination of the relative amplitudes and periods of these vibrations at various points.

3. The determination of the manner in which these vibrations became extinguished.

4. The velocity with which these vibrations were propagated.

To these observations the following may be added:—

5. Vibrations, especially those performed in a normal direction, take place more rapidly near to the commencement of a disturbance than at the end.

6. The greatest motion of the ground, as shown by the normal vibrations, is *inwards* towards the origin of the disturbance.

7. The direction in which the ground moves with the greatest velocity is also *inwards* towards the origin of the disturbance.

8. The motion does not appear to be simple harmonic.

9. The vertical motion is not due to a direct shock, but to a surface undulation.

10. The velocity of propagation of a disturbance is not constant, but varies with the distance from the origin.

The last observation led to three new sets of experiments being undertaken, the chief object of which was to determine the velocity with

which vibrations of various descriptions were propagated. The arrangements were automatic. The charges were fired electrically, and as the disturbance passed successive stations electric circuits were broken and a mark made upon the surface of a smoked glass plate which was moving at a known rate.

The results, which have not yet been worked out in detail, are generally as follows :—

1. The velocity of propagation of both normal and transverse vibrations is a function of the initial force creating the disturbance; or, briefly, the greater the charge of dynamite the greater the velocity.

2. The velocity of propagation of both normal and transverse vibrations is greater between points near to the origin than between points which are distant. Near to the origin this velocity decreases much more rapidly than it does at a distance.

When writing on this subject, I shall refer to the work done in this direction by Mr. Robert Mallet and by General Abott.

VI. *Experiments to determine the relative motion of two neighbouring points of ground.*

In these experiments two stakes were driven in the ground at various distances apart up to about 2 ft. 6 in. Sometimes the stakes were so placed that a continuation of the line joining them passed through the origin of the disturbance, and sometimes they were placed at right angles to such a direction. Fixed horizontally upon the head of one of the stakes was a light rigid bar, from the end of which a light index hung vertically. This index at a short distance below its point of suspension, which was a universal joint, was caught by a second universal joint at the end of a bar passing from the second stake. So long as the two heads of the stakes synchronised in their motions, it was assumed that the universal joints at the ends of the bars would keep vertically beneath each other, and the index which they supported would remain perpendicular. If, however, there was a want of synchronism, the lower end of the index would give a multiplied representation of their relative displacements. In all cases it was found that there was a considerable relative motion in the direction of the origin.

The chief practical value of this experiment was to see how far we are justified in placing two portions of a seismograph upon different stakes. It also shows that a building, although it may be small, may not be moved as a whole, but may suffer considerable racking.

VII. *Experiments on the Production of Earth Currents.*

From near the scene of the explosions a telegraphic communication was established across a deep moat up to a hill where the mechanical disturbances were practically not observable. Each end of this circuit was put to earth by means of two long crow-bars, and in the circuit on the hill one of Clark's differential galvanometers was arranged. As either of the crow-bars was raised or depressed it was found that the current passing through the galvanometer varied, sometimes being positive and sometimes being negative. At a certain depth, which was found by trial, the needle of the galvanometer remained at zero, and it was in this way that the adjustment to 'no current' was made previous to an explosion.

When the explosion took place, one earth bar being at distances of from 10 to 50 feet, a considerable current was always produced, and the needle of the galvanometer swung with violence until it reached a stop. The direction of swing was, in the few experiments which were made,

always constant. Sometimes the needle remained permanently deflected, and at other times it gradually fell back towards zero.

These currents I regard as being due to a mechanical disturbance of one of the earth bars, causing a difference of contact with the soil; and, in consequence of this, an alteration in the moisture, oxidation surface, &c., at one end of the circuit, thus giving rise to a difference of potential relatively to the other end of the circuit.

No doubt actual earthquakes act upon the earth plates of telegraphic lines in a similar manner, but the currents which are in this way produced at the time of an earthquake are due to different causes than those which appear sometimes to have *preceded* earthquakes by considerable intervals of time.

In the experiment upon artificial earthquakes my thanks are especially due to Mr. T. Fujioka and Mr. M. Kuwabara, of the Imperial College of Engineering, and not least of all to Mr. John Reid, agent of Nobel and Co., and to Mr. Denys Larrieu, who not only furnished me with dynamite, but on several occasions also gave me their personal assistance.

The great difficulties which had to be overcome in making these experiments, as, for instance, obtaining dynamite from the Government stores, its transportation, its storage, the difficulties in obtaining a piece of ground on which to experiment, manufacturing the necessary instruments, obtaining telegraphic wire and firing apparatus, the making of electric fuses, the anxiety lest accidents should occur, the training of a body of assistants, the putting in of bore-holes, the almost unexceptionally bad weather which had to be encountered on days for which permission had been obtained, &c., have already been referred to in a letter to this Association.

For the use of the ground where the experiments were performed and for the loan of numerous tents for the places where the instruments were established, and for a body of attentive servants, my thanks are due to His Excellency General Yamada, Minister of the Interior, and to Mr. Arai Ikunosuke, Director of the Meteorological Department. For the loan of telegraph wire, firing apparatus, and other instruments I tender my thanks to the directors and officers of the Department of Public Works, especially the Department of Imperial Telegraphs, the Naval and War Departments, and the Imperial College of Engineering.

Although several good diagrams of actual earthquake motion were obtained, in consequence of my instruments being continually removed for the purpose of making experiments on artificial disturbances, each set of which took several weeks' preparation, many earthquakes were passed by unrecorded. Had the instruments, however, been continually in their places, the records would not have been so numerous as in previous years, the last season being comparatively a poor one—there only being between May 1881 and May 1882 fifty-seven shocks, as compared with eighty which were felt during the corresponding period of the previous year.

The greatest activity was in February and March.

Although earthquake disturbances were comparatively few in the Tokio area, the records obtained by the help of post-cards from the districts north of Tokio show that during certain months there was in North Japan an activity greater than was anticipated. In fact, judging from the records which were obtained although the season was a poor one, it was calculated that, taking Japan as a whole, there were every year, on the average, two or three shocks per day, a number as great as that which is usually assigned for the whole world.

Eighth Report of the Committee, consisting of Professor E. HULL, the Rev. H. W. CROSSKEY, Captain DOUGLAS GALTON, Professors G. A. LEBOUR *and* J. PRESTWICH, *and* Messrs. JAMES GLAISHER, E. B. MARTEN, W. MOLYNEUX, G. H. MORTON, W. PENGELLY, JAMES PLANT, JAMES PARKER, I. ROBERTS, C. FOX STRANGWAYS, THOS. S. STOOKE, G. J. SYMONS, W. TOPLEY, TYLDEN-WRIGHT, E. WETHERED, W. WHITAKER, *and* C. E. DE RANCE (*Secretary*), *appointed for the purpose of investigating the Circulation of the Underground Waters in the Permeable Formations of England, and the Quality and Quantity of the Water supplied to various Towns and Districts from these formations.*

EIGHT years have elapsed since this Committee commenced to investigate the circulation of underground waters, and the quantity and character of water supplied to towns and districts so derived.

From 1874 to 1878 the Triassic and Permian formations were alone under consideration; in that year the Jurassic rocks were added to the scope of the enquiry, which at the York meeting was enlarged to include the whole of the permeable rocks in England and Wales.

The Triassic and Permian rocks of Devonshire are described in the first, fifth, and sixth reports; of Somersetshire in the first; of Leicestershire in the first, fourth, and fifth; of Warwick in the second, fourth, and seventh; of Nottingham in the second and sixth; of Cheshire in the second, fourth, and fifth; of Lancashire in the first, second, third, fourth, sixth, and seventh; of Yorkshire in the first, second, third, sixth, and seventh; of Shropshire in the sixth.[1]

Through the removal to South Africa of the member of the Committee taking charge of Staffordshire, this district is still incomplete, but some information as to the Burton-on-Trent area is given in the first report.

In Devonshire the enquiry was carried on by Mr. Pengelly, F.R.S., supplemented by details obtained by Mr. Stooke, C.E. The Triassic rocks of the district have been made the object of careful study by Mr. W. A. E. Ussher. From his investigations it would appear that the sequence exhibited has more in common with the Trias of the French side of the English Channel than with that of the midland counties. In Devonshire and Somersetshire the sandstones and conglomerates appear to have been deposited in a distinct basin to that north of the Mendips, the Keuper marls being alone common to the two districts.

The basin south of the Mendips is remarkable for having a series of marls intercalated in its sandstones, called by Mr. Ussher the 'Middle Marls'; these underlie sandstones beneath the Keuper marls. The conglomerates have a distinctly local character, and when present are plentifully water-bearing, as are the sandstones, though to a somewhat less extent.

Private supplies are obtained by wells at Torquay, where the water-

[1] *Report of British Association* for 1875 (Bristol) contains first report; that for 1876 (Glasgow) the second; that for 1877 (Plymouth) the third; that for 1878 (Dublin) the fourth; that for 1879 (Sheffield) the fifth; that for 1880 (Swansea) the sixth; and that for 1881 (York) the seventh.

level is 168 feet above the sea; at Teignmouth; at Dawlish, where the water-level is 71 feet above the sea; and at Bramford Speke, near Exeter.

Near Exeter the Lyons Holt spring issues at 126 feet above sea-level, yielding towards the town supply 47,000 gallons daily of very pure water, which is extensively used for drinking-fountains.

The following gives an abstract of the facts, of the more important wells in the Exeter district:—

Locality	Depth feet	Water-level above sea	Quantity gallons in 24 hours
Lunatic Asylum, Exminster	473½	13	200,000
Bridge Mills, Silverton	217	—	180,000
Hele Paper Works	120½	60	259,000
City Brewery	270	no inf.	4,000
Treus Weir	240	0	250,000
Kensham Mills, Hele	200	70	170,000

Higher up the valley of the Exe and its tributaries private supplies are obtained at Crediton.

North is the watershed separating the streams flowing into English and Bristol Channels.

At Willington a well 230 feet above the sea is sunk to a depth of 48½ feet; only a small quantity of water is pumped from it.

At Taunton numerous private wells give a supply of rather hard water from the New Red Sandstone.

At Somerton hard water is obtained from a well 129½ feet deep; the White Lias is said to occur in it at 90 to 99 feet.

At Wembdon a private well in triassic conglomerate yields hard water to a well 30 feet deep, at 60 feet above the sea.

At Wookey, near Wells, 70 feet above the sea, a private well, 33 feet, yields a constant supply, uninfluenced by the seasons as to quantity, but decreases 9 feet in level after dry weather.

In Bristol the wells vary in depth from 60 to 300 feet, some only penetrating peat and gravel, others passing through triassic marls, whilst a few penetrate the coal measures.

At Braysdown Colliery, near Bath, a shaft 500 yards deep, passing through New Red Sandstone and coal measures, yielded water at the bottom of the pit containing 1,008 grains of common salt, or 1,440 parts per 100,000.

In the Tiverton Coal-pit, near Bath, 16,800 gallons per 24 hours are yielded by plastic shale in the Blue Lias, 130 feet above the White Lias, which is 12 feet thick, resting on 23 feet of Rhætics, lying on the New Red Marl; the water contains 112 parts per 100,000 of common salt.

The Tyning Pit, Radstock, intersected a spring yielding 864,000 gallons per day at 200 feet from the surface, at the bottom of the Red Marls.

At Kilmersdon New Coal Shaft, Writhlington, a 10-feet shaft intersected a spring at 253½ feet. On cutting through a hard base of stone the water rose 99 feet in 24 hours, and stands at this level, yielding 98,400 gallons per day of hard water. The section passed through was liassic clay, black and blue marl 78 feet; 34 feet of 'red ground,' with bands of blue stone; conglomerate 5 feet; red beds 4 feet; then conglomerate again; the remainder of the section is not given. The late Mr. Charles Moore considered the last, 5 feet 4 inches of the Lias, in this section to belong to the Rhætic beds.

In reference to the information furnished by Mr. Taunton as to the Thames and Severn Canal, it may be well to state that the outcrop of the oolitic rocks has an average breadth on the dip of 25 miles. The base of the Oolites resting on the Lias reaches its highest point near Chipping Campden, 1,032 feet above the sea, on the watershed between the Thames and Severn basins. This, south of the Seven Wells, the source of the Churn, runs somewhat east of the base of the Oolite, causing the surface drainage of the oolitic tract around Minchinhampton, Dursley, and Wotton-under-Edge to flow into the basin of the Severn. It is probable also that a portion of the underground drainage does so also, notwithstanding the general south-easterly dip, from the basement level of the Oolites, varying in the direction of the strike, owing to the denudation of the escarpment being unequal, the Oolite to the south having been worn back much further down the dip, and consequently to a lower elevation than at Chipping Campden, descending from 1,030 at the latter place to 212 feet in the Stroud valley, or about 800 feet in 25 miles. South of this valley the level rises slightly, so that a partial discharge of underground drainage takes place in this valley, which is immediately west of the point in the Thames and Severn watershed which is penetrated by the canal connecting the two basins.

Of the 25 miles of average outcrop of oolitic rocks measured on the dip, only about 8 consist of impermeable deposits—viz., the Fuller's Earth, the Oxford Clay, and the Kimmeridge Clay,—so that two-thirds of the area may be considered to be of a permeable character. The vertical section of the Oolites is as follows:—

Portland Oolite	—
Kimmeridge Clay	—
Coralline Oolite	—
Oxford Clay	300
Cornbrash	8
Forest Marble	30
Great Oolite	200
Inferior Oolite	264

Warwickshire information.—The southern and western portion of the Warwickshire coalfield is overlaid by Permian rocks consisting of reddish-brown and purple sandstones, intercalated with marls in lenticular beds, rising to a height of 622 feet at Cowley Hall, which forms part of the watershed between the tributaries of the Trent to the north, and those of the Avon on the south.

Though the surface-drainage of this Permian area flows in opposite directions, that portion of the rainfall percolating into the ground has a uniform gradient to the south, the base of the Permians, where they rest on the coal measures west of Atherstone, being 470 feet above the sea, and 170 feet under the Mithurst Tunnel of the Midland Railway, being a fall of 50 feet per mile, while at Warwick the tops of the Permians are 186 feet above the sea, and as they are not less than 800 feet thick, their base is probably about 600 feet below the sea-level, giving a further fall of 786 feet in 18 miles, or a fall of 43 feet per mile.

Examining the district more minutely, it is seen that though the Permians do not always lie conformably on the coal measures, yet there is a general conformity, and a synclinal flexure traversing the coal measures from north to south is shared by the overlying Permians, which have synclinal dips towards the axis of an average amount of 3°,

or about 270 feet per mile from the edges of the basin towards the axis, which occurs more to the eastern than the western margin.

The fault throwing in the coal measures of Arley Wood is believed to be connected with the fault throwing back the outcrop of the main part of the coalfield at Broomfield Park; but of this there is no evidence, and as the dips in the Permian show the flexures to be present on both sides of the supposed fault, its existence is very doubtful. If it occurred, and were a watertight barrier, the water percolating into the sandstones to the west of Atherstone and flowing south would be thrown out in a line of springs, which is not the case; and there is no doubt that the waters travelling in the porous portion of the system flow south to Leamington and Warwick, where a portion of the supply is utilised. South of this point the Permians are concealed by triassic, liassic, and oolitic rocks in the direction of Banbury. Southwards the Permians probably wedge out before the Trias, which continue into the Thames basin; the water travelling down the dip planes of the Permian, where that formation thins out, probably enters the overlying triassic sands, and, prevented from rising higher by the Keuper marls, probably flows a considerable distance under the Thames basin, where its outlet being checked by the thinning out of the Lower Trias against the Palæozoic ridge, causes the subterranean Trias to be fully charged with water in a stationary condition, and thus limits the amount of absorption in the area of absorption.

Between the base of the Permian and the *Spirorbis limestone* is a thickness of 150 feet, and between it and the first workable coal is a further 500 feet, of which a large portion consists of Permian sandstone fully charged with water, which was met with in sinking the Exhall Colliery.

APPENDIX I.—*Millstone Grit Wells.*

Collected by Mr. C. E. De Rance.
From Messrs. Mather and Platt, Salford Ironworks, Manchester.

Description and thickness of each Stratum bored through at Messrs. J. & E. Grundy's, Bury.

Well 15 ft. deep

	ft.	in.		ft.	in.	
At	15	0	from surface	30	0	of Blue metal
,,	45	0	,,	19	2	,, Black shale and rock
,,	64	2	,,	0	10	,, Coal
,,	65	0	,,	2	0	,, White rock
,,	67	0	,,	18	0	,, Dark grey rock
,,	85	0	,,	3	0	,, Black rock
,,	88	0	,,	2	6	,, Dark grey rock
,,	90	6	,,	3	0	,, Brown rock
,,	93	6	,,	9	6	,, Blue metal
,,	103	0	,,	14	6	,, Dark grey rock and blue metal
,,	117	6	,,	2	0	,, Coal
,,	119	6	,,	5	0	,, Fire-clay
,,	124	6	,,	0	6	,, Brown rock
,,	125	0	,,	19	0	,, Blue metal
,,	144	0	,, (48 yds.)	1	0	,, Coal
,,	145	0	,,	82	10	,, Dark grey rock
,,	227	10	,,	1	8	,, Fine clay and white rock
,,	229	6	,,	28	6	,, White rock
,,	258	0	,,	10	0	,, do. and a few partings
,,	268	0	,,	10	0	,, do.

Well 15 ft. deep.

	ft.	in.		ft.	in.	
At	278	0	from surface	3	0	of Dark brown rock
„	281	0	„	7	6	„ White rock
..	288	6	„	1	6	„ Millstone rock
,	290	0	„	0	8	„ Dark brown rock
„	290	8	„	4	10	„ do.
„	295	6	„	7	6	„ White rock
„	303	0	„	1	6	„ Dark brown rock
„	304	6	„	7	6	„ White rock
„	312	0	„	3	0	„ Shale or blue metal
„	315	0	„	300	0	Total depth bored
	315		from surface			

Collected by Mr. C. E. De Rance.
From Mr. A. Timmins, Stud. Inst. C.E., Runcorn.

1. Leyland Local Trial Boring for Water, Clayton-le-Woods. **1a.** Dec. 1881.

3, 5 feet well to	64	feet
14 inch boring to	120	feet
10 „ „	150½	feet

3a. None. **4.** 14½ feet from surface. **4a.** Same. **8.** Made by Dr. Campbell Brown, county analyst, Jan. 28, 1882.

	Parts per 100,000
Total solid matter	37·4
Organic carbon	·093
Organic nitrogen (Dr. Frankland's method) .	·019
Ammonia	·015
Ammonia for organic matter	·008
Nitrates and nitrites	·046
Total combined nitrogen	·078
Combined chlorine	3·02

Hardness 24, of which 20·1 was temporary.

	ft.	in.
9. Surface soil	3	0
Sandy gravel	13	0
Boulder clay	30	0
Ferruginous earth	1	0
Fine light sand	2	0
Coarse gravel	5	0
Micaceous clay	5	0
Purple shale	1	0
Ferruginous sandstone	3	0
Uniform sandstone	27	0
Brown mould	5	0
Purple shale	19	0
Purple sandstone	13	0
Bronze shale	3	0
Purple shale	20	6
	150	6

Appendix II.—*Triassic Wells.*

Collected by Mr. Thos. S. Stooke, Assoc. M. Inst. C.E.
From Mr. Edwin Parry, Engineer to Messrs. Marshall, the proprietors of the said well. October 19, 1881.

1. In the mill-yard belonging to Messrs. Marshall, Shrewsbury. **1a.** 1837. No. **2.** About 240 feet. **3.** 60 feet; from the bottom of the well are two bore-holes 50 yards deep, through which the whole supply comes, 9 in. diam. **3a.** The well enters

the rock 11 ft. **4.** 40 feet of water in well which we have pumped out in an hour. 10 hours. **5.** 250,000 gallons. **6.** Some slight variation in rainy weather. Yes; it has diminished about one-fourth. **7.** Yes. Appears to rise when Severn is in flood. **8.** Only the hardness; by Clarke's test 18°. **9.** 48 feet of clay and sand. Red sandstone to bottom of bore. **10.** Yes. **11.** Yes, by cast-iron cylinders. **12.** Geological Survey shows a fault N.W. close to the well. **13.** No. **14.** No. **15.** No.

Collected by Mr. Thos. S. Stooke.
From Mr. C. Hy. Kynaston, Brewer, Wem, Salop.

1. Sunk 17 feet. Bored from bottom diameter of hole 3 inches. **1*a*.** 1878. No. **3.** 17 feet, 6 feet, and 100 feet. **3*a*.** None. **4.** 14 feet from surface. 2 hours. **4*a*.** 14 feet from surface. **5.** From 4 to 5,000 gallons. **6.** Does vary a little in September and October, when it is the lowest. **7.** Yes; in about 24 hours. **8.** None. Used for brewing purposes. **9.** None; gravel, then blue clay down to water, 15 inches of sand 100 feet from surface from which the water came.—T. S. S. **12.** None, **13.** None. **14.** Not within 17 miles. **15.** No.

Collected by Mr. Thos. S. Stooke.

1. At Messrs. Marshall & Co.'s Bleach Works, Hanwood. **1*a*.** In progress. **3.** 68 feet; 4 feet 6 diam. **3*a*.** None. **4.** Rises to top. **5.** 48 gallons per minute. **7.** No. **8.** Soft. **9.** Red marl and blue-grey sandstone. **10.** No. **15.** No.

Collected by Mr. Thos. S. Stooke.
From Mr. R. E. Johnston, C.E., Engineer Office, G.W.R. and L.N.W. Joint Railways, Birkenhead.

1. Steam Shed, Wellington G.W. & L.N.W. joint railway companies. **1*a*.** Finished August 1875. **2.** Above 350 feet. **3.** 18 feet below soil level; 36 feet below original surface. Bore-hole 163 feet below original surface. **3*a*.** None. **4.** One foot below rail-level. After pumping 14 feet below rail-level. Two hours. **4*a*.** One foot below rails, or 19 feet below surface-level; at present time height of water 18 feet. **5.** 204,000 gallons per day of 24 hours. **6.** Nothing perceptible. **7.** Slightly, after several days' rain. No information. **8.** Good for general purposes.

9.	Drift	45 feet
	Sandstone	78 „
	Red marl	22 „

9*a*. In sandstone. **10.** Yes. **11.** Yes. **12.** None. **13.** None.

Collected by Mr. Thos. S. Stooke.
From Lieut.-Col. Drake, R.E.

1. Barrack enclosure, Shrewsbury. **1*a*.** March 1882. No. **2.** +239·01· O.D. **3.** Total depth 93 feet; diameter 37 feet × 6 feet 3 inches and 56 feet × 5 feet 5 inches. Bore-hole 243 feet 6 inches × $5\frac{1}{2}$ inches diameter. **3*a*.** No drift-ways. **4.** 75 feet to surface of water. **4*a*.** 75 feet, which it maintains. **5.** 175,000. 7,000. **6.** No variance has been detected. **7.** No. The water in well stands 6 feet 4 inches above adjoining River Severn.

8.	Lime	Large	Ammonia	Trace
	Magnesia	Present	Nitric acid	Large
	Chlorine	„	Nitrous acid	Trace
	Sulph. Acid SO_4	„	Oxidisable matter	Present
	Phosphoric acid	None	Iron	None

Hardness.

Fixed	7°·35
Temporary	5°·40

		ft.	in.
9.	Soil	3	0
	Coarse gravel	7	0
	Red sand	3	0
	Yellow loam	2	0
	Fine red sand	35	0

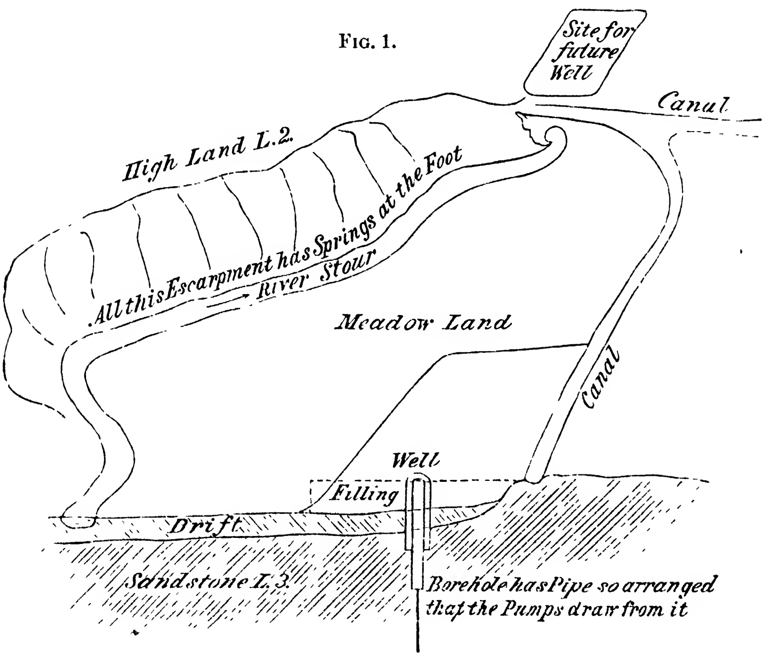
	ft.	in.
Coarse gravel	1	0
Fine sand	3	0
Fine gravel	5	0
Stony red clay	13	0
Blue stiff stony clay	3	0
Coarse gravel	11	0
Red sandstone	157	6

9*a*. Principal yield of water from last 50 feet of boring. **10.** First spring of water met in last gravel bed-75 to 86 feet. **11.** No. **12.** Yes; a large fault trending E.N.E. to due west. **13.** No. **14.** No knowledge of any. **15.** Not aware of any.

Information given by Mr. E. B. Marten, Member of the Committee, Engineer to Stourbridge Waterworks Co., &c.:—

1. Wollaston Station of the Stourbridge Waterworks at Coalbournbrooke, between Wordsley and Stourbridge, on the road to Wollaston Hall, and between Canal and River Stour, just under the *Platts* on Ordnance Survey. **1***a*. 1880, July 44 ft. deep, and bore-hole 179 ft.; May 1882 sunk 20 ft. deeper. **2.** 218 ft. above sea-level. **3.** Well 44 ft. from surface; bottom of bore-hole 179 ft. from surface. **3***a*. No drift-ways. **4.** Water rises over the surface, and flows into River Stour. If pumped

FIG. 1.



empty well fills in 25 minutes. If pumped down 4 ft. it rises and overflows in 3 minutes. A pipe fixed in bore-hole can be shut off from the well, and the water rises 10 or 12 ft. above the surface in good volume, but it has not been tested as to what height of pipe would prevent overflow. **4***a*. The first 10 ft. only were dry, and then the water increased very fast. **5.** 600,000 when pumped about 20 ft. below surface; average 300,000 gallons per day at about 4 ft. below surface. **6.** No variation can be observed, and no diminution. **7.** Rain makes no difference; ordinary level stands about 10 ft. above River Stour, which is about 100 yds. away. **8.** Practically the same as at Mill Meadow. The waterworks were originally set out here, but moved nearer the town to a well still used, and which has served for 20 years. **9.** This drift then all Upper Mottled Sandstone. **9***a*. Red sandstone rock is of uniform

texture, a little more at about 43 ft. from surface. **10.** No surface spring in drift, but if holes are made they fill with water. **11.** Land springs are coffered out. **12.** No faults are seen near the well. **13.** No brine. **14.** No. **15.** No. **16.** The new red sandstone occupies a large area from the western boundary fault of the South Staffordshire coalfield to Enville, and forms the gathering ground for this well. It has few large streams on it, as it is so permeable that the rainfall percolates easily. There are no large towns on this area, but villages and gentlemen's country seats, including Enville Hall, Lord Stamford's, and the famous Sheep Walks. The rock is full of water, which overflows along the banks of the river, and the long overflow has formed springs or wells in the sandstone escarpment, one of which is called the 'bottomless pit,' from the persistency of the outflow of the water in great volumes at all seasons uniformly. This company purchased the right to run a heading at 50 ft. below the surface from the Wollaston well under this escarpment to another site at Tack Farm, half a mile away, but the bore-hole has yielded all that is needed without any chance of river water getting into the well. The Wollaston site was that originally chosen for the works, but it was considered that the same condition would appertain at Mill Meadow, the site near the town, although no sign of a spring was then seen. It was found exactly as conjectured, and answered for town supply for 20 years, and being between the town and reservoir a much less outlay was sufficient.

Stourbridge Waterworks (continued):—

1. At the Mill Meadow Pumping Station, near Stourbridge, $\frac{1}{4}$ mile N.E. of centre of town. **1*a*.** Sunk in 1856 to depth of 50 ft., with a bore-hole 20 ft. from the bottom of the well. In 1871 it was deepened to 50 ft., with bore-hole 80 ft. deeper, and drift-ways made; two other shafts were also sunk for convenience. **2.** Surface of the ground or engine-house floor 237 ft. above the sea (Ordnance datum). **3.** 50 ft. to bottom of the well. 130 ft. to bottom of bore-hole. **3*a*.** 44 ft. Length about 40 yards. **4.** Water would rise to the surface and flow over into the River Stour, but a drain-pipe is put into the river about 10 ft. from the surface. When pumping 300,000 gallons per day it sinks 20 ft. and fills again in two hours. When pumping 550,000 gallons 30 ft., and recovers in four hours. **4*a*.** The water rose to surface and flowed over, and would do so again. **5.** About 600,000 gallons per 24 hours. **6.** No difference in seasons. After 15 years it was tested and found to yield exactly the same quantity. **7.** Local rain does not affect it. It stands 10 ft. above the River Stour.

FIG. 2.

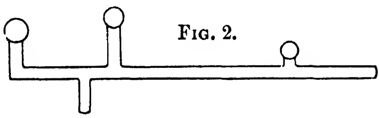
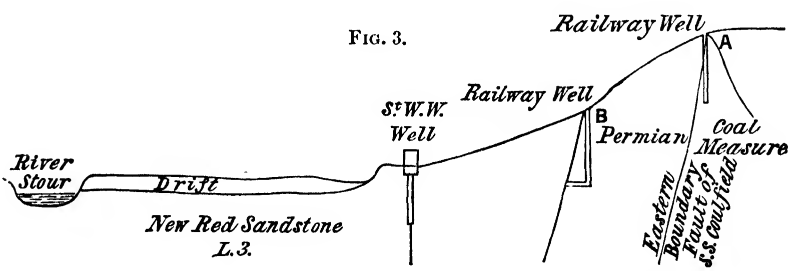


FIG. 3.



8.

	Grs. per gal.
Carbonate of lime	15·23
Sulphate of lime	0·47
Sulphate of magnesia	1·67
Chloride of sodium and alkalies	1·76
Organic matter	2·07
Loss	·77
Degree of hardness	17·2
	21·95

This site was chosen as it was conjectured that the rock was as overflowing as the more distant site at Wollaston originally chosen. This has been suffused in 20 years,

and being between the town and the high-level reservoirs it saved much outlay. The gathering ground for this well is supposed to be the Clent Hills, and the large sandstone area of Hagley and Clent Heath. **9.** No drift. Well was commenced in the dock. The new red sandstone, 3 ft. **9*a*.** Water comes chiefly out of the bore-holes. **10.** No springs, but if any hole was made it would fill with water. **11.** As the well is generally *full* land-springs cannot come in. New pumping stations are purchased to prevent the need of drawing down this water permanently. **12.** The Western boundary fault of the S. S. coalfield, 200 yards to east. **13.** No brine springs. **14.** None near. **15.** No wells stopped because of brine. **16.** Two wells near are also shown on the sketch.

Wolverhampton Waterworks.

(*From Memorandum taken by Mr. E. B. Marten when he was Resident Engineer to Wolverhampton Waterworks, during which time this Shaft was sunk. Section is given in Vertical Sections, Sheet* 50 *of the Geological Survey.*)

1. At Goldthorn Hill in Wolverhampton, on high ground where Service Reservoir is placed. **1*a*.** 1853; not altered since. **2.** 506 above mean sea-level. **3.** 300 ft.; 8 ft. diam.; 340 ft. bore-hole; 640 ft. altogether. There are two shafts near to each other. One used for sinking and the other for pumping. **3*a*.** 240 ft. main driftway 990 ft. long to the west branch, 330 ft. to the south. Total 1,330 ft. **4.** The greater part of the water was at 240 ft., and the pumps were shortened to that point. Water had to fill the headings when it rose, and so it took some time. **4*a*.** No note of this to be found. There was not much until 240 ft.

5.	January to June 1852 . . .	26,615,888	gallons pumped
	July to December . . .	28,095,268	„
	Total 1852 . . .	54,711,156	
	January to June 1853 . .	36,981,792	gallons pumped
	July to December . . .	48,808,261	„
	Total 1853 . . .	85,790,050	

This was nearly all that could be pumped. **6.** Only being used for local supply of some high-level houses there is not much pumped out. **7.** I believe not. **8.** No certain information, but average quality of sandstone water. **9.** See No. 50, pit section Geological Survey. The shaft is in Permian strata, and near Western boundary of S.S. coalfield, which is ½ mile to the east. **9*a*.** Chiefly in 240 ft. water-bearing strata. **10.** No; it is on a hill. **11.** All surface water is kept out. **12.** The great boundary fault of S.S. Coalfield, ½ mile to East. **13.** The bore-hole yielded strong brine. **14.** No. **15.** No **16.** Not much used now, but perfectly good water, the borehole being stopped up.

Wolverhampton Waterworks (continued):—

(*From Memorandum taken by Mr. E. B. Marten when he was Engineer to the Wolverhampton Waterworks Company.*)

1. Tettenhall, 2½ miles west of Wolverhampton. **1*a*** 1847. Not altered since. **2.** 372 Ordnance datum. **3.** 136 ft. 10 ft. diam. oval to suit pumps. 2 other shafts for convenience. **3*a*.** 130 ft. about ¼ mile in different directions under the company's land. **4.** From 5 to 19 ft., according to pumping. See paper attached with results of some years' pumping. **4*a*.** See above details. **5.** Full quantity possible was pumped during the years of which details are given.

Mr. Marten's Notes of Wolverhampton Waterworks Well at Tettenhall, August 4, 1882.

	Total Pumped gals.	Average per day gals.	Depth of Water in Well ft.	in.
1847 June to Dec. . . .	8,571,596 . .	42,224 . .	19	6
1848 Jan. to Dec. . . .	20,095,110 . .	57,636 . .	17	1
1849 „ . . .	37,495,670 . .	102,727 . .	16	6
1850 „ . . .	56,484,162 . .	154,750 . .	8	0
1851 „ . . .	61,804,904 . .	169,328 . .	8	0
1852 „ . . .	56,474,656 . .	154,725 . .	7	0
1853 „ . . .	61,445,552 . .	168,344 . .	6	0
1854 „ . . .	57,206,412 . .	156,812 . .	5	0

6. No. **7.** No. **8.** No certain information, but good average sandstone water. **9.** On a hill. No drift, all sandstone 5 ft. Section would be sent if desired. **9a.** Towards the bottom. **10.** No. **11.** No land springs, as well was on a hill. **12.** No. **13.** No. **14.** No. **15.** No. **16.** The well is not now so much used, as the Cosford works described by Mr. H. J. Marten supply most of the water.

Particulars of a Bore-hole sunk under Mr. H. J. Marten's superintendence for the Waterworks belonging to the Corporation of Wolverhampton.

By Mr. Henry J. Marten, M. Inst. C.E.

1. The Bore-hole in question is situate at the Cosford Pumping Station of the Wolverhampton Corporation Waterworks, about nine miles distant from Wolverhampton along the old turnpike road leading from Wolverhampton to Shrewsbury, and is sunk through the upper soft red, and the conglomerate, into the lower soft red measures of the New Red Sandstone formation.

1*a*. The boring was commenced in June, 1876, and completed in December, 1877, and it has not been deepened since.

2. The approximate height of the present surface of the ground above mean sea-level is 200 feet.

3. The total depth of the bore-hole from the present surface of the ground is 918 feet 9 inches, of which 534 feet is 24 inches in diameter, and the remainder, 384 feet 9 inches, is 15 inches in diameter.

The bore-hole is fitted at the top with a cast-iron guard pipe which rises about 3 feet above the present surface of the ground, with an opening in it at a depth of 4 feet, and another at between 16 and 17 feet below the present surface of the ground, through which, by means of sluices, the water rising up the bore-hole can be turned either into an adjoining brook or into the engine well.

3*a*. There are no horizontal driftways.

4. When not being drawn upon the water rises in the guard pipe described in reply to question 3, to a height of about 1 foot above the present surface of the ground, or 9 feet above the natural, or original, surface of the ground. At this level, which is denominated the summit level, the artesian force of the deep springs supplying the bore-hole is balanced by the head of water attained in the guard pipe, and everything is at rest. On opening the sluice 5 feet below this point the natural discharge from the bore-hole is at the rate of 480,000 gallons a day. On opening the lower sluice in the guard pipe, so as to reduce the outflow point to the level of the water in the engine well, or 14 feet below summit level, the natural discharge is at the rate of 830,000 gallons a day. On pumping down the water in the bore-hole to a depth of 27 feet below summit level, the yield is at the rate of 1,320,000 gallons a day, and at 31 feet below summit level, it is at the rate of 1,420,000 gallons a day. On ceasing to pump and shutting the sluices, the water rises in the bore-hole to summit level in a few minutes.

4*a*. Excepting for experimental purposes, the water in the bore-hole has not been permanently pumped down below the engine well level, and when not drawn upon the height at which the water now stands is the same as when the well was first sunk.

5. The average discharge at engine well level is between 800,000 and 900,000 gallons a day, and this quantity is daily pumped from that level.

6. The level of the water does not appear to vary with the seasons to

any appreciable extent, and it has not diminished since the bore-hole was completed.

7. The ordinary level is not affected by local rains. The summit level to which the water rises is about 5 feet above the surface of the water in the River Worf, a stream which is within a dozen yards of the bore-hole.

8. The analysis of the water is as under :—

	Grains per gallon
Total solid matter	18·970
Albuminoid ammonia	0·000
Free ammonia	0·000
Nitrogen, as Nitrates and Nitrites	0·059
Chlorine	0·980
Hurtful metallic impurity	none
Transparency	good
Hardness—Temporary	6·46
„ Permanent	6·69
„ Total	13·15

The water does not contain any marked peculiarity.

9. The section of the rocks passed through is as under :—

	ft.	in.	ft.	in.
Drift			nil.	
Upper Mottled Sandstone			461	6
Pebble Beds :—				
Upper pebble beds	165	6		
Argillaceous marl rock	85	0		
Lower pebble beds	128	0		
			378	6
Lower Mottled Sandstone (not bottomed)			78	9
			918	9

The Pebble Beds, it will be seen, are here divided into upper and lower beds by a thick bed of argillaceous marl. The lower pebble bed was of so obdurate a character that 2,000 blows with a heavy cutter weighing nearly one ton, and falling 5 feet each stroke, only penetrated one foot through it.

9*a*. The principal springs intercepted were in the upper soft red rocks. There is generally a large flow from the springs in the lower soft red rocks, but in this case the artesian force at command at the engine well level was not sufficient to liberate them to any appreciable extent. The object in view in opening a communication through the argillaceous marl and conglomerate beds into the lower soft red rocks was to ensure a supply from the last-named beds in the event of the engine well being lowered, a work now being carried out.

10 and 11. There is no drift rock over the site of the bore-hole.

12. There are no large faults in the neighbourhood of the bore-hole. The borehole is situate in the central portion of the downfall trough between the Shropshire and Staffordshire coalfields—the boundary faults of which are respectively eight and nine miles from the bore-hole.

13. There was a very slight briny ooze, estimated at about 300 gallons a day, from the argillaceous marl beds into the bore-hole.

14. There are no salt springs in the neighbourhood.

15. No wells or borings have been discontinued in the neighbourhood in consequence of the water being more or less brackish.

16. The bore-hole required no casing in it from top to bottom. The bore-hole, which was sunk by rope-boring machinery, supplied by Messrs.

Mather and Platt, of Manchester, cost 2,315*l.*, or at the rate of about 2*l.* 10*s.* per foot run. The total expense, including the last-named amount —the balance valve, the fuel for engines, guard pipe and sundry labour, was about 3,700*l.*

Particulars of Waterworks Well sunk under superintendence of Mr. HENRY J. MARTEN, M. Inst. C.E., *for the supply of Tamworth and the surrounding district with water.*

1. The well is situate at Hopwas, about 2 miles to the west of Tamworth, and is sunk in the conglomerate beds of the New Red Sandstone formation.

1*a*. The well was sunk in the year 1879, and has not been deepened by sinking or boring since that date.

2. The approximate height of the surface of the ground is 306 feet above Ordnance datum.

3. The depth from the surface of the ground to the bottom of the well, which is 10 feet in diameter, is 168 feet, and there is no bore-hole.

3*a*. There are no horizontal drifts.

4. Before pumping, the water stood at 129 feet below the surface of the ground. The number of hours elapsing before ordinary level is restored depends upon the extent and duration of the pumping.

4*a*. The well was sunk practically dry, until a depth of 168 feet below the surface of the ground was reached, when, through the marl floor of the well at that depth a large spring was met with, the initial inflow of which was at the rate of about 1,500,000 gallons a day, and its artesian force such that in a very few minutes it rose to a height of 39 feet above the bottom of the well, or, as before stated, to 129 feet from the surface of the ground, at which point it remained stationary, and to which point it rises when not drawn upon by pumping.

5. During an experimental test extending over a period of 59 days, from September 21 to November 19, 1881, the pumps were kept continuously at work day and night, and during that time the total quantity of water raised from the well was 61,000,000 gallons, or rather over 1,000,000 gallons a day. This continuous pumping at the rate named lowered the water in the well 28 feet 7 inches, or to a depth of 157 feet 7 inches below the surface of the ground, leaving a depth of 10 feet 5 inches in the well. On the cessation of pumping the water rose 8 inches in 30 seconds, or at the rate of 945,000 gallons a day, and at the end of 8 days it had regained 14 feet 2 inches of the loss of level. In 3 weeks (notwithstanding occasional pumping for the supply of about 800 houses then laid on), it had risen to a level some few inches higher than the point at which it stood before the experimental test was made. The average quantity pumped for the supply at present of between 1,100 and 1,200 houses is about 55,000 gallons *per diem.*

6. There is no decided information available as to whether the water-level varies with the seasons. I am of opinion that it does, though only to a limited extent. The well having only been regularly drawn upon for water supply purposes for less than a year, and that at a rate very far within the margin of its average yield, affords no experience at the present time on the point whether the yield is diminishing or not.

7. The ordinary water-level is not affected by local rains. It stands

about 177 feet above mean sea-level, or 11 feet above the ordinary summer level of the river Tame, about half a mile distant.

8. The analysis is as under :—

	Grains per gall.
Temporary hardness	6·13
Permanent ,,	3·50
Total ,,	9·63
Chlorine	1·61
Total solids	25·06

The water contains no marked peculiarity.

9. The section of the rock passed through is as under :—

	ft.	in.
a. Soil, sand, and gravel	16	6
b. Red marl, with layers of sandstone	15	11
c. Hard conglomerate rock	5	7
d. Argillaceous marl rock	39	11
e. Fissured sandstone	13	9
f. Argillaceous marl rock	5	0
g. Light fissured sandstone rock	30	4
h. Red marl, with layers of greyish blue stone, and balls of marl of same colour with dark spot in centre, called 'fish-eyed' marl	41	0
Total	168	0

9*a*. As stated in reply to 4*a*, the well was practically dry until the spring referred to was tapped, at a depth of 168 feet from the surface; though a little water oozed out at the bottom of the fissured sandstone rock '*g*' in the preceding answer.

A singular phenomenon occurred with respect to one of the fissures situate in this rock at 115 feet from the surface of the ground. When first opened down to, a violent current of wind (simply atmospheric air) rushed from it, which gradually spent itself, and was followed thereafter at one time by an in-draught, succeeded at another by an out-draught. It was observed that these variations of direction were coincident with barometrical changes—i.e. when the barometer was rising there was a decided indraught from the well into the fissure; and, on the contrary, while the barometer was sinking there was a decided out-draught from the fissure into the well. It is evident, therefore, that the fissure must be connected with large cavernous passages. Changes in the weather were accurately foretold by watching the behaviour of a candle-flame when placed near the fissure; but the workmen were disinclined to place much faith in its indications until an active outflow during the whole of one day was succeeded at night by one of the most violent storms of the period.

10. The cover-drift over the rocks contains no springs.

11. There are no land springs to keep out of the well.

12. There is a large down-throw fault between the well and the river Tame, which brings the Keuper Marl beds face to face with the conglomerate beds in which the well is sunk.

13. No brine springs were passed through in making the well.

14. There are no salt springs in the locality.

15. No wells or borings in the neighbourhood have been discontinued in consequence of the water being more or less brackish.

16. The well is lined with brick in cement to within about 2 feet of the bottom. Its cost was 793*l*. 15*s*. 6*d*.

Information collected by Mr. James Plant, F.G.S. From Mr. H. W. Pochin.

1. Croft, Leicestershire. This is an underground spring in greenstone rock at bottom of a deep cutting. **1***a*. Begun 1880. Water struck January 1, 1882. **2.** About 320 ft. **3.** 110 ft. **4** and **4***a*. Water issues constantly at the end of the fissure, and has been running without ceasing for eight months. **5.** A pump is now used which discharges 100,000 gallons every ten hours. **6.** Quantity is the same as when first struck. **7.** Is below the level of the River Soar, which runs close by. **8.** No proper analysis yet made, but water very soft.

		ft.	in.
9.	Lower boulder clay	8	0
	Upper white Keuper sandstone	30	0
	Red marl separated by thin floors of white sandstone	92	0
	Total	130	0

These beds lie on the worn and rounded surface of the greenstone, at an angle of about 20° dipping S.E. **9***a*. Greenstone. **10.** None seen. **12.** No. **13.** No. **14.** No. **15.** No. **16.** Six photographs have been taken, and will show the deep spring issuing out of the rock.

Information collected by Mr. James Plant. From the Hinckley Local Board.

1. Hinckley Wharf, near Hinckley, Leicestershire. **1***a*. Boring of 10 inches diameter commenced Nov. 1881. **2.** 313 ft. **3.** Depth from surface of 10 inches diameter 160 feet, depth below this 540 feet of 7 inches. Total depth 700 feet. **4.** The mean height at which the water stands in the bore-hole varies from 630 to 680 feet. **5.** Over 1,000 gallons were taken out of the bore-hole, which filled up again in about two hours. **6.** See No. 4. **7.** Water-level is above the bed of the River Anker, which is about 2 miles S.W. of the bore-hole. **8.** No analysis yet made.

9. *Hinckley Wharf Boring, commenced Nov.* 1881.

Character of Rocks	Thickness of Beds		Total Depth		Remarks
	ft.	in.	ft.	in.	
Soil	1	0	1	0	
Middle glacial sands . . .	30	0	31	0	
Lower boulder clay . . .	50	0	81	0	
Red boulder clay . . .	7	0	88	0	Many pebbles.
Upper Keuper sandstone . .	12	0	100	0	Much denuded. Band fine crystallised gypsum 6 in.
Red and blue marl with gypsum	10	9	110	9	
Red marl and gypsum . . .	69	8	180	5	
Grey sandstone	1	1	181	6	
Red marl and gypsum . .	26	11	208	5	
Grey sandstone	1	6	209	11	6 in. crystallised gypsum.
Red marl and gypsum bands	96	7	306	6	
Grey sandstone	0	9	307	3	5 in. gypsum. Very abundant water.
Red marl and gypsum bands .	46	5	353	8	3 in. gypsum.
Grey sandstone	1	0	354	8	4 in. gypsum.
Red marl and gypsum . .	41	0	395	8	
Grey rock, mottled marl and gypsum	100	4	496	0	At 484 ft. crystallised gypsum 3 in., being last band of gypsum.
Red micaceous sandstone .	11	0	507	0	Top of Waterstones. Fine clay or wayboard ½ in.
Soft micaceous red sandstone .	4	6	511	6	

Character of Rocks	Thickness of Beds		Total Depth		Remarks
Mottled marly sandstone (mica) .	5	6	517	0	½ in. wayboard.
Grey mottled marly sandstone .	15	1	532	1	Ripple marks.
Soft red sandstone . . .	11	7	543	8	
Red sandstone	6	10	550	6	Fine red clay, wayboard.
Red sandstone	10	6	561	0	Fine red clay, wayboard 1 in.
Red sandstone (mica) . .	5	5	566	5	
Fine red clay	4	0	570	5	
Red sandstone	9	0	579	5	
Fine red clay	1	0	580	5	
Red sandstone	7	0	587	5	
Fine red clay	0	6	587	11	
Grey sandstone (mica) . .	2	5	590	4	
Fine red clay	5	1	595	5	
Light red sandstone (mica) .	6	0	601	5	
Red sandstone	2	0	603	5	Wayboards 1½ and 6 in.
Soft white sandstone, with small yellow iron spots . . .	18	4	621	9	
Hard white coarse sandstone with false bedding . . .	4	1	625	10	
Soft white sandstone with small iron stains	7	5	633	3	
Hard white siliceous sandstone .	2	2	635	5	
Hard red siliceous sandstone .	3	6	638	11	
Soft white clay	3	4	642	3	
Red micaceous sandstone and red sandy marl . . .	6	8	648	11	
Red marl and sandstone . .	11	4	660	3	
White and brown sandstone .	11	6	671	9	
Brown micaceous sandstone and strong red marl . . .	10	6	682	3	Wayboard.
Red micaceous sandstone and strong red marl . . .	6	0	688	3	Wayboard.
Soft red clay	2	6	690	9	
Brown micaceous sandstone .	0	7	691	4	
Soft red clay	1	6	692	10	
Brown sandstone . . .	0	10	693	8	
Red clay	2	1	695	9	
Red sandstone	1	2	696	11	
Red clay	1	7	698	6	
Red and brown micaceous sandstone	4	0	702	6	
Red clay	2	2	704	8	
Red micaceous sandstone . .	0	6	705	2	

10. Yes. **11**. Entirely out. **12**. One great fault three miles to the W. is known, and another large one suspected four miles to the E. These faults run from N.W. to S.E. **13**. No. **14**. No. **15**. No. **16**. Several chalybeate springs formerly existed (shallow wells penetrating into the drift), they are all now disused but one.

Collected by Mr. E. Wethered, C.E.

From Mr. J. N. Taunton, C.E., F.G.S., Engineer to the Thames and Severn Canal.

1. Thames Head, three miles south-west of Cirencester. **1*a*.** About 1793. **2**. 364 feet. **3**. 63 feet depth of well; shape oval 15 ft. x 10 ft. No bore-hole below bottom of well. **3*a*.** Original drift-way 30 yds. subsequently extended down the valley some 500 yards tailing into cutting about 17 feet in depth. **4**. and **4*a*.** The water-level varies from 30 to 53 feet below the surface, according to the season and pumping. When the engine pumps continuously it usually lowers the water-level

gradually *in a dry season* 3 or 4 inches a week. As the springs break in the neighbourhood the water rises rapidly. There does not appear to be any material change in the normal level of the water. **5.** The quantity of water pumped from 1,500,000 to 3,500,000 gallons per diem. **6.** Apart from the continuous pumping for the supply of the summit-level of the Thames and Severn Canal the water-level is determined by that in the gravel in the bed of the adjoining valley, and rises and falls with it. No perceptible diminution during the last 30 years. **7.** Not affected except by long-continued rains in the Cotteswold District on the N.W. **9.** Section sent herewith. **9a.** In the basement beds of the Great Oolite. **10.** See section. **11.** See section. **12.** No. **13.** No. **14.** No.

APPENDIX III.—*Jurassic Wells.*

Collected by Mr. C. Fox Strangways.
From Lieut.-Col. W. F. Walker, R.E., York.

1. Towthorpe Common, near York. **1a.** January to April 1879. No. **2.** 60 feet. **3.** The well consisted of a bore-hole 9 inches in diameter and 311 feet 4 inches deep. This was subsequently plugged, leaving the present depth 210 feet. **3a.** None. **4** and **4a.** Enquiry will be made on these points. **5.** Not tested. After 72 hours continuous pumping no diminution in supply was perceptible. **6.** Little or no variation is observed in the shallow wells of the locality. Experiment not tried in deep boring. **7.** Only *temporarily* affected. Ordinarily stands 15 feet above the level of the water in the Fors, the nearest river. **8.** Two copies of the results of the analysis of this water are attached, that marked No. 1 being the result of the first analysis, and that marked No. 2 being the result of the analysis after plugging for about 100 feet had been resorted to.

Analysis No. I.

From Towthorpe, York.	Drawn December 20, 1879.
Source, Artesian well, 311 ft. 4 in. deep.	Received December 26, 1879.

Physical Characters.

Colour (through 36 in.)	Faintly yellow.	Lustre	Fair.
Turbidity	None.	Taste	,,
Sediment	Present.	Smell	None.

Hardness.

Fixed	66°·50
Temporary or removable	26°·25
Total	92°·75

Quantitative Chemical Analysis.

	Parts per 1,000,000
Oxygen required for oxidisable organic matter	0·5600
Ammonia, free	0·4940
Ammonia, albuminoid	None.
Nitric acid (NO_3)	0·2297
Nitrous Acid (NO_2)	None.
Total nitrogen included in nitrates and nitrites	0·0519

	Grains per Gallon
Volatile organic matter	0·4357
Ammonium nitrate	0·1517
Sodium nitrate	0·1566
Sodium chloride	2·5689
Sodium carbonate	5·0000
Calcium carbonate	14·8000
Calcium sulphate	77·9800

	Grains per Gallon
Magnesium sulphate	25·7295
Sodium silicate	1·9485
Aluminium and iron phosphates	2·8300
Water with calcium sulphate	10·3209
Total solids	141·9218
Total solids	141·9218
Total solids by evaporation	141·8500
Difference	0·0718

The microscopic examination of the sediment shows mineral grit and sand, some crystalline particles, probably carbonate of lime, a little mycelium of fungi, but no trace of animal or vegetable life.

This water is quite unfit for a water-supply on account of the large quantity of limė, magnesia, and sulphuric acid. Perhaps if the borings were continued further a softer water might be obtained.

Attention is called to the case of the Clifton Asylum Well, where the solids are now only about 20 grains, whereas I believe that previous to deepening the water was too hard to use.

F. De Chaumont, M.D., F.R.S.,
Professor of Military Hygiene,
Army Medical School.

Laboratory, Army Medical School,
Royal Victoria Hospital, Netley,
January 24, 1880.

Analysis No. II.

From Towthorpe, York.
Source, well 210 feet.

Drawn April 10, 1880.
Received April 14, 1880.
Examined April 20, 1880.

Physical Characters.

Colour (through 18 ins.)	Slightly yellow.	Lustre	Very good.
Turbidity	None.	Taste	Good.
Sediment	Large.	Smell	None.

Chemical Analysis.

Qualitative (*water unconcentrated*).

Lime	Very large.	Ammonia	Large.
Magnesia	Very large.	Nitric acid	Large.
Chlorine	Trace.	Nitrous Acid	None.
Sulphuric acid	Very large.	Oxidisable matter	Trace.
Phosphoric acid	None.	Iron or lead	None.

Hardness.

	Degrees of Clark's Scale
Fixed	57°·75
Temporary or removable	30°·15
Total	87°·50

Quantitative.

	Grains per Gallon
Volatile matter (by incineration and after re-carbonating)	1·7500

	Parts per 1,000,000
Oxygen required for oxidisable organic matter	0·5800
Ammonia, free	0·4548
Ammonia, albuminoid	0·0960
Nitric acid (NO_3)	8·5529
Nitrous acid (NO_2)	0·2300

N.B.—These constituents, with the oxidisable organic matter indicated by the oxygen required are included in the *Volatile Matter.*

Total nitrogen included in nitrates and nitrites 1·5497

	Grains per Gallon
Chlorine	1·6368
Calcium carbonate	20·1000
Fixed hard salts	57·7500
Sulphuric acid (SO$_4$) 53·0 880 total partly included in fixed hard salts	54·5632
Alkaline carbonates	
Sodium or other metal (combined with Cl or SO$_4$) not included in fixed hard salts	
Silica, alumina, iron, &c.	
Total solids (by evaporation)	135·8000

MICROSCOPIC CHARACTERS.—The microscopic examination shows only a little mineral grit. No trace of animal or vegetable life.

REMARKS.—The water has improved a little since plugging, and justifies further plugging, as originally suggested, to the level of the green sand.

J. L. NOTTER, M.D., F.C.S.
Assistant Professor of Military Hygiene

Laboratory, Army Medical School,
Royal Victoria Hospital, Netley.
April 23, 1880.

		ft.	in.
9.	Top sand	4	6
	Fine clay	15	0
	Boulder clay	15	0
	Loamy sand	6	0
	Fine warp clay	9	0
	Grey sand	10	0
	Boulder clay	4	0
	Green sand	16	0
	Green sand with layers of blue bind	18	0
	Blue bind or marl	1	9
	Light green sand with blue bind	35	0
	White sandstone	5	0
	Blue bind	1	0
	Red marl	2	0
	White sandstone	81	0
	Blue marl	0	6
	White sandstone	23	0
	Blue marl	0	3
	Variegated sandstone	60	0
	Red marl	3	0
		310	0

NOTE.—The actual depth is 311 ft. 4 in., but 1 ft. 4 in. has been lost in taking the various dimensions. See remark opposite 3, as to plugging.

10. Yes; the drift is full of water. **11.** Yes. **12.** No. The strata are those of the Vale of York. **13.** None. **14.** None. **15.** None; as far as we know.

Collected by Mr. C. Fox Strangways.
From Mr. J. W. Woodall, J.P., F.G.S.

1. Salton, near Malton, York, N. Riding. **1***a*. 1880. No. **2.** 150 ft. **3.** 316. About 4 in. **3***a*. None. **4.** Flows out at surface. **4***a*. Flows out at surface. **5.** Not been tested. **7.** A few feet above the Rye; 3 or 4 ft. **8.** No analysis has been made, but it is slightly sulphureous. **9.** Fluviatile drift 15 ft. Kimmeridge clay, about 295 ft. **10.** No. **11.** Yes.

APPENDIX IV.—*By* Mr. E. WETHERED, F.G.S., F.C.S.

The Porosity and Density of Rocks.

My first object in commencing a series of observations on the porosity of rocks was with a view of investigating the lithological changes which

are brought about by the percolation of water through them. But while engaged in work of this kind, one is struck with the great volume of water which the rocks of the earth are capable of absorbing, and a knowledge of this is important both as regards water-supply and the suitability of stone for building purposes. Much information on the subject has already been obtained by the investigations of the Rivers Pollution Commission, the Commission on Water Supply, and on the Selection and Decay of Stone for the Houses of Parliament. Also by the Committee appointed by the British Association for the Investigation of the Circulation of Underground Waters, and by Mr. De Rance, C.E., F.G.S., in his book on the Water Supply of England and Wales.

The method which I have adopted for arriving at the results contained in this paper is that recommended by Dr. Sterry Hunt in the Geological and Chemical Essays.[1] The portions of rock selected for the work were struck off by a blow with a hammer. By this means I was enabled to get clear and natural surfaces exposed. The whole of the results obtained are given in the annexed table.

The Arenaceous Rocks.—The oldest rocks which I have examined are those of the Old Red, and all the specimens were selected personally. Taking first the Old Red Sandstone we get an average specific gravity of 2·61, but the specimens from near Bristol have a decidedly lower specific gravity compared with others which are given. Excluding the flags from Caithness, the volume of water absorbed by a cubic foot of the rock is 0·707 of a gallon, or 59,000,000 gallons to the square mile 3 feet thick. The specimen of flags from Caithness absorbed much less water, and I found the same thing to apply to Old Red flagstones from other districts. The conglomerate beds are more absorbent than the sandstones: the average specific gravity is 2·58 and the volume of water absorbed by a cubic foot 0·805 of a gallon, or 67,000,000 gallons to a square mile 3 feet thick.

I next take the Millstone Grit. The specimens from Bristol, South Wales, and the Forest of Dean were selected personally, and for those from Sheffield I am indebted to the kindness of Dr. Sorby, F.R.S. The Millstone Grit which underlies the Bristol coalfield is something like 1,000 feet thick[2]; the chemical composition, the mean of five analyses, is as follows:—

Silica	97·80
Alumina	·47
Oxide of Iron	·80
Lime	·44
Carbon	·17
Carbonic acid	·39
Moisture	·22
	100·29

In some of the specimens of this grit, microscopically examined, the grains of silica appear to cement themselves together, and so closely, that it is difficult to distinguish their outline. The grains are, for the most part, sub-angular, and are either colourless or have a slight pink tinge imparted by oxide of iron. The specific gravity averages 2·60, and the amount of water absorbed by a cubic foot of the rock is 0·080 of a gallon, equal to 6,000,000 gallons to a square mile 3 feet thick.

[1] Pages 165–7.
[2] *Proc. Bristol Naturalists' Society*, 1875–6, page 336.

Two typical specimens of Millstone Grit were selected from Pertyrch, South Wales; one a coarse variety and the other with grains averaging about 0·010 of an inch in diameter. There is a slight lithological difference when compared with the same formation around Bristol, and chemically it is a little more argillaceous, as shown by the following analysis:—

Silica	96·63
Alumina	1·15
Oxide of iron	·70
Lime	·55
Carbonic acid	·20
Carbon	·30
Moisture	·10
Alkalies not estimated	—
	99·63

The specific gravity may be taken at 2·57, the volume of water capable of being absorbed by a cubic foot of the rock 0·290 of a gallon, or 23,000,000 gallons to a square mile 3 feet thick.

The specimens of Millstone Grit from Sheffield resemble lithologically those of South Wales, though a person acquainted with the formations in the two districts would probably be able to distinguish between them. The grains composing the grit in the neighbourhood of Sheffield, according to Dr. Sorby, 'are, on the whole, extremely angular.'[1] The specific gravity averages 2·59, and the volume of water absorbed per cubic foot of rock is 0·504 of a gallon, equal to 42,000,000 gallons to a square mile 3 feet thick.

Two samples of Millstone Grit were collected from the Forest of Dean coalfield; one from the southern outcrop and the other from the northern. We here get a very different lithological character when compared with the same formation at Bristol and in South Wales, and a very much larger volume of water is absorbed. The rock resembles a Trias sandstone more than the Millstone Grit, but in chemical composition there is practically little difference, as is shown by the following analysis of a specimen from Drybrook:—

Silica	98·06
Alumina	·30
Oxide of iron	·50
Lime	·33
Carbon	·20
Carbonic acid	·30
Alkalies	Trace
	99·69

The specific gravity of the Forest of Dean Millstone Grit averages 2·63, the volume of water absorbed by a cubic foot of the rock is 0·854 of a gallon, or 71,000,000 gallons to a square mile 3 feet thick. Though I have given the average volume of water absorbed, it will be seen, on reference to the tabulated list, that the results obtained from the two specimens examined differ considerably. In the case of the one absorbing the greatest quantity of water, the grains composing it were but slightly cohesive, but in the other case the rock was of a more compact character.

[1] *Quarterly Journal Geol. Society*, 188, page 64.

Referring to the upland surface water from the Millstone Grit and the non-calcareous portions of the coal measures, the Royal Commissioners on Rivers Pollution say in their sixth report,[1] 'Many of the large manufacturing towns of Lancashire and Yorkshire are supplied with water for potable and manufacturing purposes, by the storage in vast reservoirs of the upland drainage from these formations. Being but slightly absorbent they yield to the impounding rivulets and streams a large proportion of the actual rainfall.' Though the Millstone Grit may be but slightly absorbent in the localities named, yet this character cannot be established as a rule by which one can be guided. In the case of the Bristol coalfield it applies, but when we come to the Forest of Dean we find the reverse to be the case. The Millstone Grit of the West of England serves as a good illustration of the variability of rocks in different localities, especially as regards the volume of water which is capable of being stored in them.

The next rocks examined were those of the Pennant Grit. It is necessary here to lay stress upon the definite article, as 'the Pennant' is confined to the middle coal-measures of Bristol, and is also extensively developed in the Somersetshire and South Wales coalfields. There are, however, beds of grit in the lower coal-measures of Bristol, which are lithologically true Pennants. The Pennant Grit is a compact blue rock, made up of angular grains. The following is the mean analysis of seven samples taken from my paper on the 'Composition of the Pennant Grit.'[2]

Silica	84·96
Alumina	4·34
Oxide of iron	4·55
Lime	1·29
Carbon	2·86
Carbonic acid	1·33
Magnesia	·05
Water	·58
	99·96

The specific gravity of the Pennant averages 2·67, the water absorbed by a cubic foot of the rock 0·150 of a gallon, and by a square mile 3 feet thick 12,000,000 gallons. Speaking of deep wells in the Coal Measures, the Rivers Pollution Commissioners say:[3] The proportion of mineral impurity present in the deep well-water is always large, but varies within wide limits. The water was found to contain, 'as a rule, larger proportions of organic elements (organic carbon and organic nitrogen) than are met with in similar waters obtained from other strata,' the average proportion being 0·153 parts per 100,000 parts, or ·107 grains per gallon. I quite endorse what the Commissioners say in respect to water from the coal-measures generally, but where we have a great thickness of rock, as in the case of the Pennant around Bristol and Swansea, I think there may be an exception to what has been stated. Some years ago, it was proposed to supply a portion of Bristol with water from the Frampton Cottrell iron mines, which are in the Pennant, and the analyses made of the water showed it to be of good quality. Considering the quantity of water which this rock is capable of storing, the quality

[1] Page 40, part 2.
[2] *Journal of the Chem. Society*, 1882, page 79.
[3] Sixth Report, page 91.

becomes a matter of great importance to villages and towns in the vicinity.

The only specimen of Triassic sandstone which I have had an opportunity of examining is that of the Bunter, from Heidelberg, Germany. The specific gravity was 2·55, and the volume of water absorbed by a cubic foot of the rock was 0·838 of a gallon, equal to 70,000,000 gallons to a square mile 3 feet thick. Mr. I. Roberts, F.G.S.,[1] has made observations on the porosity of the Bunter from the Pebble Bed of Everton, and found the absorption to be 0·733 of a gallon of water to the cubic foot of rock.

The Calcareous Rocks.—Coming to the calcareous rocks which I have examined, I have classed among them the Magnesian Conglomerate, which I take first. The average specific gravity is 2·73, and the volume of water absorbed by a cubic foot of rock varies between 0·082 and 0·368 of a gallon, or between 6,000,000 and 30,000,000 gallons to a square mile 3 feet thick. This rock is extensively used for building purposes, and a knowledge as to the porosity of the various beds is therefore important in this respect as well as for water supply. It would appear from the specimens which I have examined, that the finer the conglomerate the more water there is absorbed.

Of the Magnesian Limestone, two specimens were examined, both selected from the same locality. The average mean specific gravity is 2·77, the water absorbed by a cubic foot of the rock 1·031 gallons, and by a square mile 3 feet thick, 86,000,000 gallons.

The Magnesian Limestone is much more porous than the Carboniferous Limestone, which I take next. All the specimens were obtained personally, the first three from the lower shales. These gave a specific gravity of 2·71, with a porosity of 0·028 of a gallon of water to a cubic foot of rock, which is equal to 2,000,000 gallons to a square mile. The specific gravity of the specimens representing the limestone gave an average of 2·70. The volume of water absorbed by a cubic foot was ·043 of a gallon, or 3½ million gallons to a square mile 3 feet thick. From these comparisons it would seem that the lower shales are least porous. Considering the large volume of water which these rocks supply, their not being porous will seem contradictory; the fact is, however, that the water finds its way through joints and fissures, dissolving away the limestone, and sometimes forming subterranean reservoirs.

We next come to rocks which are very pervious; some of them, so far as their absorption of water is concerned, may be compared to an ordinary sponge. The rocks to which I allude are those of the Oolites. The specimens of the Great Oolite were personally selected from near Bath. The average specific gravity is 2·52, the water absorbed by a cubic foot of rock 1·706 of a gallon, or 142,000,000 gallons to a square mile 3 feet thick. The soft variety is the most absorbent. The specimens of Inferior Oolite were personally selected from near Cheltenham, with the exception of one from near Bath. As this rock is so extensively used for building and on account of the great volume of water which the beds contain, I have examined a number of representative specimens, but the variation in the porosity is so great that no reliable average can be given of the volume of water capable of being absorbed. The bed which absorbed the least was a hard variety of Oolite taken from below the Pisolite bed of Leckhampton Hill, near Cheltenham; and the bed which absorbed the most was a soft variety of freestone from the same locality, but higher

[1] Fourth Report Underground Water Committee, page 16.

up in the series. The first of these gave 0·146 of a gallon to the cubic foot, or 13,000,000 gallons to the square mile 3 feet thick; and the second 2·202 gallons to the cubic foot, or 184,000,000 gallons to a square mile 3 feet thick. We may, therefore, take it that the yield of water from the Inferior Oolite varies between those limits.

The Relation of Specific Gravity to Porosity.—In the report on Selection and Decay of Stone of the Houses of Parliament in 1839[1] it is said that the specimens of rock which had the greatest specific gravity absorb the least quantity of water, though there are individual exceptions. I cannot say that my observations bear out this rule, and I doubt whether any such rule can be laid down.

The Relation of the Size of Grains composing a Rock to the Porosity.—In the tabulated results I have given a column in which the size of the grains composing the rocks is given. The object of this was to ascertain whether any relation existed between the size of the grains and the porosity. In the sandstones and grits there appears to be no connection whatever, but in the Magnesian Conglomerate the finer the material of which a bed is made up the more water there seems to be absorbed. In the case of the Oolites the more compact the rock the less porous it becomes.

The Purity of the Water.—On account of shallow well-water being almost invariably contaminated with organic matter, the Royal Commissioners on Rivers Pollution have classed shallow well-water as dangerous. On the other hand, deep well-water is classed as wholesome. It is, therefore, clear, that if shallow well-water is dangerous and deep well-water wholesome, there must be a purifying process going on during the percolation of water through the strata. I have given the analyses of samples of Millstone Grit and of the Pennant Grit, and on an examination of these it will be seen that the grits are practically composed of grains of silica. There is, therefore, nothing in the chemical composition of the rock which could purify the water except mechanically, and in order to get rid of organic contamination there must be oxidation. We must, therefore, look to another source than the chemical composition of the rock for the oxidising agent, and I think it will be found in the air absorbed by the water and in the air contained by the rock. The water in the strata is constantly being drained by springs, wells, and outlets by which the water-level is reduced. During a dry period, then, the interstices of the upper portions of porous rocks must be either occupied by air or there must be a vacuum. The former of these two conditions is the most probable, and it seems reasonable to assume that the oxygen of this air must oxidise any organic matter contained in water percolating through the earth. I have made observations with a view of ascertaining the volume of air absorbed by certain rocks. I have endeavoured to arrive at the result by displacing the air contained in given specimens by water. I have found the volume of water absorbed, and reduced it to the weight of air, assuming that water at 62° F. is 819·4 times heavier than air at the same temperature. By this means I find that a cubic foot of Inferior Oolite, absorbing 1 gallon of water, would, in the event of complete drainage off of the water, absorb 0·16 of its volume of air. In short, we find in the rocks of the earth much the same process going on naturally as the London water companies are doing artificially for the filtration of

[1] Page 36.

TABLE OF THE DENSITY AND POROSITY OF ROCKS.

Geological formation examined	Locality	Size of grains in decimals of an inch	Specific gravity of the mass, water = 1	Specific gravity of the particles, water = 1	Volume of water absorbed by 100 volumes of rock	Gallons of water absorbed per cubic foot of rock	Gallons of water absorbed per square mile of rock 3 feet thick
Old Red Sandstone . . .	Bristol	Irregular ·009 to ·004	2·59	2·89	10·30	·642	53,754,000
" " . . .	"	·007	2·57	2·86	9·97	·622	52,000,000
" " . . .	Gloucestershire . .	·008	2·60	2·96	11·60	·723	60,538,000
" " . . .	" . .	—	2·63	3·04	13·53	·844	70,610,000
Old Red Flags	Caithness . . .	—	2·66	2·70	1·39	·086	7,254,000
Old Red Conglomerate . .	Gloucestershire . .	—	2·62	3·22	18·79	1·172	98,000,000
" " . . .	" . .	—	2·60	2·96	11·60	·723	60,536,000
" " . . .	" . .	—	2·63	3·04	13·53	·844	70,610,000
" " . . .	" . .	—	2·62	2·93	10·29	·642	53,701,000
" " . . .	" . .	—	2·63	2·97	11·43	·713	59,651,000
" " . . .	" . .	—	2·42	2·81	11·84	·738	61,791,000
Millstone Grit	Bristol	·003	2·63	3·01	1·66	·103	8,663,000
" "	"	·003	2·57	2·61	1·34	·083	6,993,000
" "	"	·006	2·62	2·64	·93	·058	4,853,000
" "	S. Wales . . .	Very coarse and irregular in size	2·55	2·70	5·70	·355	28,747,000
" "	"	·010	2·60	2·69	3·62	·225	18,892,000
" "	Sheffield	·009	2·60	2·81	7·54	·470	39,350,000
" "	"	·014	2·59	2·84	8·65	·539	45,142,000
" "	Forest of Dean . .	·009	2·65	2·90	9·44	·589	49,265,000
" "	"	·011	2·62	3·19	17·94	1·119	93,625,000

Pennant Grit	Bristol	·004	2·67	2·73	2·24	·139	11,690,000
„ „	„	·011	2·68	2·73	1·63	·101	8,506,000
„ „	„	·009	2·65	2·73	2·86	·178	14,925,000
„ „	S. Wales	—	2·66	2·71	2·18	·136	11,377,000
„ „	„	—	2·69	2·50	3·18	·198	16,595,000
Coal Measure Grit (Pennant Type)	Bristol	·005	2·69	2·74	1·18	·112	9,446,000
Ditto, same quarry	„	·007	2·74	2·75	·68	·042	3,548,000
Coal Measure Grit (Millstone Grit Type)	„	·006	2·60	2·72	4·39	·273	22,910,000
Bunter Sandstone	Heidelberg	—	2·55	2·94	13·43	·838	70,889,000
Mag. Conglomerate	Clifton	Coarse	2·74	2·78	1·34	·082	6,993,000
„ „	„	„	2·74	2·80	2·14	·133	11,168,000
„ „	„	Fine	2·72	2·86	5·28	·329	27,555,000
„ „	„	„	2·73	2·90	5·90	·368	30,791,000
„ „	S. Wales	Coarse	2·73	2·80	2·36	·147	12,316,000
„ Limestone	Clifton	—	2·80	3·24	16·33	1·018	85,223,000
„ „	„	—	2·75	3·30	16·74	1·044	87,363,000
Carb. Limestone, L.S.	„	—	2·70	2·71	·17	·010	887,000
„ „ „	„	—	2·70	2·71	·41	·025	2,139,000
„ „ „	„	—	2·74	2·76	·79	·049	4,122,000
„ „	„	—	2·70	2·72	·50	·031	2,609,000
„ „	„	—	2·72	2·74	·70	·043	3,653,000
„ „	Gloucestershire	—	2·70	2·73	·92	·057	4,801,000
Great Oolite	Bath	Hard	2·59	2·98	23·62	1·473	123,268,000
„ „	„	„	2·39	3·14	23·88	1·490	124,625,000
„ „	„	Soft	2·60	3·98	34·57	2·157	180,415,000
Inf. „	„	—	2·67	3·80	29·72	1·854	155,103,000
„ „ Building Stone	Cheltenham	—	2·67	3·51	23·98	1·496	125,147,000
„ „ „ „	„	—	2·69	3·21	16·22	1·012	84,649,000
„ „ Soft Freestone	„	—	2·55	3·94	35·29	2·202	184,172,000
„ „	„	—	2·67	2·91	8 22	·512	42,898,000
„ „ Limestone	„	—	2·68	3·15	12·15	·758	63,481,000
„ „ Pisolitic	„	—	2·70	2·76	2·3	·146	12,264,000

the London water-supply. The following is a section of the filter beds of the Chelsea Waterworks, for which I am indebted to the manager, Mr. Lott :—

	ft.	in.
Fine sand	3	6
Shells [1]	0	4
Shingle	2	0
Coarse shingle [2]	2	2
Total [3]	8	0

The chemical analysis of the top bed of the filter, which does the work, gave the following :—

Silica	90·05
Alumina	·40
Oxide of iron	6·90
Carbonaceous matter	·70
Carbonic acid	1·50
Magnesia	·01
Alkalies	trace
Moisture	·26
	99·97

The rate of filtration is 2 gallons per hour.[4] By comparing the chemical analysis of the filter-bed with those of the Millstone Grit and of the Pennant Grit, it will be seen that to all practical purposes the analyses are the same. There is nothing in the chemical composition of the filter which can oxidise the organic impurities of the Thames water passing through, but the oxidation is effected by air between the grains of sand with perfect effect. It is much the same with water percolating through the rocks of the earth; it comes in contact with air collected in the interstices. With such rocks as the Mountain Limestone, however, where the water yielded comes through fissures and joints in the strata, and does not percolate, it is a question whether the purifying process would be always satisfactory.

Appendix V.—*List of Queries circulated.*

1. *Position* of well or shafts with which you are acquainted? **1a.** State *date* at which the well or shaft was originally sunk. Has it been deepened since by sinking or boring? and when? **2.** Approximate *height* of the surface of the ground above Ordnance Datum (mean sea-level)? **3.** *Depth* from surface to bottom of shaft or well, with diameter? *Depth* from surface to bottom of bore-hole, with diameter? **3a.** *Depth* from the surface to the horizontal drift-ways if any? What is their length and number? **4.** *Height* below the surface, at which water stands *before* and *after* pumping. Number of hours elapsing before ordinary level is restored after pumping? **4a.** *Height* below the surface at which the water stood when the well was first sunk, and height at which it stands now when not pumped? **5.** *Quantity* capable of being pumped in gallons per day of 24 hours? Average quantity daily pumped? **6.** Does the *water-level* vary at different seasons of the year, and to what

[1] To keep the upper layer from mixing with the lower.

[2] Gradually increases in coarseness towards the base to prevent the pipes which carry off the water from becoming clogged.

[3] The arenaceous material is taken from the Thames, and is well cleansed by a powerful hose playing upon it.

[4] Colonel Bolton's Report for February, 1882, for which I am indebted to the courtesy of Colonel Bolton.

extent? Has it diminished during the last ten years? **7.** Is the ordinary *water-level* ever affected by local rains, and, if so, in how short a time? And how does it stand in regard to the level of the water in the neighbouring streams, or sea? **8.** *Analysis* of the water, if any. Does the water possess any marked *peculiarity?* **9.** *Section* with nature of the rock passed through, including cover of Drift, if any, with *thickness?* **9a.** In which of the above rocks were springs of water intercepted? **10.** Does the cover of Drift over the rock contain *surface springs?* **11.** If so, are these *land springs* kept entirely *out* of the well? **12.** Are any large *faults* known to exist close to the well? **13.** Were any *brine springs* passed through in making the well? **14.** Are there any *salt springs* in the neighbourhood? **15.** Have any wells or borings been discontinued in your neighbourhood in consequence of the water being more or less *brackish?* If so, please give section in reply to query No. 9. **16.** Kindly give any further information you can.

Report of the Committee, consisting of Dr. H. C. SORBY, Professor W. RAMSAY, *and* Professor W. J. SOLLAS, *appointed for the purpose of investigating the Conditions under which ordinary Sedimentary Materials may be converted into Metamorphic Rocks. Drawn up by* Professor W. J. SOLLAS (*Secretary*).

THE Committee have entered upon this investigation by commencing a study of the effect of highly-elevated temperatures and pressures on the solubility of minerals and chemical compounds ordinarily insoluble in water.

They have succeeded in obtaining a simply constructed tube, in which the experimental substances can be heated in the presence of water to a high degree of temperature (300–400° C.) without the escape of steam. The tube consists of cast iron, is 4 in. long, with an internal diameter of $\frac{3}{4}$ in., and walls $\frac{3}{8}$ in. thick; the mouth is closed by a conical iron stopper ground to fit, and secured by screws and nuts to a marginal flange; to ensure complete tightness a washer of copper, or other soft refractory metal, is introduced before screwing up.

Silica is the first substance which has been selected for examination, and the experiments with it have only recently been taken in hand. They have been conducted by Mr. Hunter, under the supervision of Professor Ramsay, in the laboratory of University College, Bristol.

(1) A fragment of colourless, transparent quartz was reduced to fine powder, placed in a cage of platinum wire gauze, and so introduced into the tube, along with 10 cubic centimetres of water. The tube was then closed, and heated by a Bunsen's burner to a temperature of 300° C. for two days. There was no sign of action; no residue was left on evaporation of the water, and the surface of the quartz retained its lustre.

(2) Some powdered chalcedony taken from a clear hyaline specimen was similarly treated. It was slightly attacked, and on evaporation a distinct residue was left.

(3) Some chemically pure silica was next prepared by precipitation from sodium silicate with hydrochloric acid, evaporation to dryness, thorough washing, and subsequent ignition. After ignition it was placed in the experimental tube, and heated to 300° C. for two days. At the conclusion of the experiment the impalpable powder of silica was found to have caked together into a white opaque granular mass. On examina-

tion under the microscope it was found to have passed into a state of glass. The glass itself is transparent and colourless, and hard enough to scratch ordinary window-glass; it is, however, filled with innumerable oval and tubular cavities, so as to resemble pumice, and it is to these that it owes its whiteness and opacity when seen by the unassisted eye. It is now in process of chemical examination.

It is proposed to continue these experiments on silica, particularly under much higher temperatures than those hitherto employed, and to extend them to other substances.

Report of the Committee, consisting of the late Professor A. LEITH ADAMS, Professor W. BOYD DAWKINS, Dr. JOHN EVANS, Mr. G. H. KINAHAN, *and* Mr. R. J. USSHER (*Secretary*), *appointed for the purpose of carrying out Explorations in Caves of Carboniferous Limestone in the South of Ireland.*

WITHIN the past three months attempts have been made to effect an entrance from the face of the scarp into the series of caves discovered and reported on last year (1881) in the rock called the Carrigmurrish, but after a careful survey had been made, and levels taken from the several branches of the caves by Mr. Duffin, County Surveyor (whose kind assistance we wish specially to acknowledge), it was found that the caves lay at so low a level as to make such a mode of access to them practically impossible. The only entrance to them continues to be by the difficult descent within the rath on the top of the rock. A series of trial pits were then sunk with candle-light in the several branches of the caves. Beneath the stalagmite floor was in all cases a deep layer of tenacious clay, passing into gravel when the pits were sunk to the depth of about six feet. No animal remains nor other relics occurred in these trial pits.

It is therefore probable that the only objects of interest that will be yielded by excavations on the Carrigmurrish will be found in the kitchen-midden of the rath, much of which remains untouched.

Our next operations were conducted in the Bone cave of Ballynamintra, which yielded remains of man associated with those of Irish elk and bear in 1879, as reported in the 'Proceedings of the Royal Irish Academy for 1880,' and more fully in the 'Transactions of the Royal Dublin Society for 1881.'

In this cave a new chamber was cleared out down to the level of the stalagmite floor, and a portion of the latter was broken up, but as yet without result. Beyond this chamber, however, a new series of chambers were discovered in which no excavations have been made.

Excavations have therefore been carried on during the past season only to a very limited extent, owing to unusual demands on time and labour for other purposes. The amount expended in wages, &c., is but two pounds.

The ossiferous caverns in the county of Waterford have not, however, been exhausted. The Shandon Cave, which yielded so many fossil

remains of mammoth, bear, horse, reindeer, and other animals, remains in great part unexplored since the excavations of our late lamented friend Professor A. Leith Adams in 1875. He was then prevented from prosecuting his work further by the danger of the impending roof coming away in fragments, the rock being full of horizontal splits, so that layers of stone are ready to fall if disturbed from beneath. Professor Leith Adams was anxious to resume the exploration of this great cavern, which has been so fruitful in Pleistocene mammalia, and stated it as his opinion that the superincumbent rock should first be wholly removed for a distance of fifty feet along the face of the cliff, taking the present mouth of the cave as the centre, and as far in as Cullen's Chamber might extend. The cliff is over twenty feet in height, so that such an undertaking would involve considerable outlay, including compensation to the occupier of the ground. If, however, your Committee could undertake to have the work quarried at sixpence a cartload, the stone thus obtained might be sufficient recompense for the injury to land and fences. A very large quantity of stone would have to be removed, which could be done during the winter months, leaving the floor of the cavern open for excavation before next summer. It is difficult to estimate the probable expenses of this work. To do it effectively the cave should be properly opened up by the total removal of its roof. Professor Leith Adams expended 40*l.* on the portion that he excavated in 1875, without having to remove any of the roof, as his operations were conducted near the mouth. A sum of 50*l.* seems to be required for the work now proposed.

Report of the Committee, consisting of Sir A. C. RAMSAY, Professor J. PRESTWICH, Professor T. MCK. HUGHES, *and* Mr. W. TOPLEY, *appointed to assist in the preparation of an International Geological Map of Europe. Drawn up by* Mr. W. TOPLEY (*Secretary*).

SINCE the appointment of the Committee last year considerable progress has been made with the Geological Map of Europe. The International Geological Congress met at Bologna on September 26 last. Two members of this Committee, Professor Hughes and the Secretary, attended the meeting. The discussions extended over five days, but it is only with those immediately referring to the Map that this Committee is concerned.

The Congress resolved to prepare and publish a Geological Map of Europe, with so much of Asia and Africa as comes within the border: the map to be published at Berlin on the scale of 1 : 1,500,000 (about 23 miles to the inch). A Committee to carry out the work was appointed as follows:—

MM. Beyrich and Hauchecorne for Germany (Directors of the Map).
M. Daubrée for France.
M. De Moeller for Russia.
M. Giordano for Italy.

M. Mojsisovics for Austria-Hungary.
Mr. Topley for England.
M. Renevier, as Secretary of the Original Committee on Map Colouring.

The details of the execution of the map were left to the Committee, as also were some questions relating to colouring. The Congress, however, decided upon the following colours:—

Rose carmine for crystalline schists, whenever there is no certain proof that they are of Cambrian or Post-Cambrian age.

Bright rose colour for rocks of Pre-Cambrian age.

Pale rose colour for crystalline rocks of indeterminate age.

Violet for Trias.

Blue for Jurassic (the Lias a darker tint.)

Green for Cretaceous.

Yellow for Tertiary, the higher beds being the lighter shades.

The subdivisions of a system are to be represented by shades of the colour adopted, the darker shade representing the older subdivision. Divisions may also be shown by reserved spaces of white or by lines.

The lettering for sedimentary rocks to be based on the Latin alphabet; for eruptive rocks on the Greek alphabet.

The monogram of a system to be formed by the initial capital of the name of the system; subdivisions to be denoted by the initial small letter of its name in addition to that of the system. Smaller divisions to be denoted by figures, one denoting the oldest example:—Silurian, S; Ludlow, S^{l}; Upper Ludlow, S^{l_2}.

The use of palæontological, orographical, chronological, petrographical, and geotechnical signs is recommended.

The arrangements finally made for the publication of the map are as follows:—Reimer and Co., of Berlin, are the publishers. The map will be issued in forty-nine sheets (7 by 7); the size of the entire map when joined together will be rather over 12 ft. by 10 ft. The British Isles are contained within two sheets, with a slight extension of the south-west of Ireland beyond the map-margin. The southern sheet contains a large part of the north and north-west of France.

The cost of engraving and colouring the map, including the preparation of 1,000 complete copies, is estimated at 4,000*l.* To meet this expense contributions will be given by the various Governments of Europe. England's share of the expense is 400*l.*, for which 100 copies of the complete map will be given. The Royal Society has voted the first instalment of 75*l.* from the Government grant; and has also given 75*l.* towards the cost of preparing the map in England so as to be ready for engraving, and of printing the reports of the various sub-committees on Geological Nomenclature, &c.

England is also to supply the requisite information for the topography and geology of Palestine.

The engraving of the map is well advanced. Streams and railways are given in great detail; the names of places of geological interest will be inserted; also the names of the mountain chains and the heights of the chief summits (in metres).

Tenth Report of the Committee, consisting of Professor J. PRESTWICH, Professor T. McK. HUGHES, Professor W. BOYD DAWKINS, Professor T. G. BONNEY, Dr. CROSSKEY, Dr. DEANE, and Messrs. C. E. DE RANCE, D. MACKINTOSH, R. H. TIDDEMAN, J. E. LEE, JAMES PLANT, W. PENGELLY, H. G. FORDHAM, *and* W. TERRILL, *appointed for the purpose of recording the position, height above the sea, lithological characters, size, and origin of the Erratic Blocks of England, Wales, and Ireland, reporting other matters of interest connected with the same, and taking measures for their preservation. Drawn up by* Dr. CROSSKEY, *Secretary.*

THE Committee have received the following accounts of Erratic Blocks examined during the past year:—

Yorkshire.—Mr. Woodall has examined a number of boulders brought from the bottom of the North Sea north of Flamborough Head, and gives the following account of their position and character:—

North of Flamborough Head large numbers of boulders are found strewing the bottom of the North Sea; but they are arranged very much in a belt, which is approximately parallel to the existing coast, at a distance of twenty to forty miles from the land. The outer or eastern edge of this belt is not well defined; but on the western side it would appear to have a sharper boundary, as the marks used by the trawlers to avoid the boulders show that the line is well marked.

While preserving a line parallel to the existing coast, it is curious to note that just opposite to the mouth of the Tees the inner edge of the 'rough ground'—by which name this belt is known to the fishermen—makes a sharp bend to the eastward, coinciding almost exactly with a line drawn down the Tees Valley. I venture to suggest that this large belt of erratic blocks is connected with the history of the giant glacier which descended the Tees Valley, bringing, among other stones, masses of the well-known Shap Fell granite. The boulders that I have seen brought on shore—having been trawled up by the smacks—are either of Shap granite or carboniferous limestone, and of these I have examined from sixty to seventy specimens. The rough ground—as far as I am aware—extends from the coast of Northumberland to the mouth of the Humber. While the boulder clay on the coast line contains blocks of carboniferous limestone and Shap granite, the glacial deposits in the valley of the Rye and Derwent—south of the Cleveland Moor district—are composed of oolitic and liassic detritus, and are very different from those on the coast, though only a few miles distant from each other.

Warwickshire.—A remarkable group of erratic blocks has been exposed in some excavations made for building purposes in Icknield Street, Birmingham, between Key Hill and Hockley Hill. The section occurs on the N.W. slope of the hill on which it is exposed, and consists of 7 feet or 8 feet of glacial drift (the height slightly varying at different points), which immediately rests on an irregular and broken surface of the new red sandstone of the district, and is composed of about 1 foot 6 inches of surface soil. The 'drift' itself consists of erratic blocks,

intermixed with numerous round and oval stones and pebbles, together with small gravel, sand, and clay. In different parts of the section these materials occur in varying proportions, a light clay generally predominating. The erratic blocks, however, so pervade the whole bed, and so thoroughly constitute a component part of it, that they cannot have been dropped into it either singly or by twos and threes. They must all have travelled together, for a certain distance at any rate, and have been brought down together to the spot at which they are found. They consist of—

Felsites.
Felspathic ashes.
Shales and flagstones.
Quartz conglomerates.
Fragments of quartzite.
Millstone grits (with Stigmaria).
Fossiliferous calcareous sandstones of Llandovery age.

The felsites and the felspathic ashes are the most abundant, and the Llandovery sandstones are the rarest. No granite has been found in this group of erratics.

The sizes of the blocks vary. The measurements of a few of the largest are as follows:—

20 in. × 20 in. × 8 in.; 26 in. × 15 in. × 14 in.; 28 in. × 29 in. × 10 in.; 32 in. × 18 in. × 16 in.

Some are subangular; a not inconsiderable proportion are well smoothed, although they can hardly be said to be highly polished; and on a few striæ may be traced.

Professor C. Lapworth has examined the specimens, and recognises a large number as being of rocks that occur *in situ* at the Berwyn Hills; others may be found in the Arenig range.

The condition of the new red sandstone rock on which the boulders rest is most remarkable. The sandstone rock is broken up; and large fragments of it have been lifted up out of their position and thrust into the middle of the drift. At one point in the section a part of the rock has been lifted up almost like an arm, and still remains united with the basement mass, while the drift fills the V-shaped hollow. A large erratic block is seen close to the extreme end of the uplifted arm of the basement rock.

The evidence of violence is complete. The breaking up of the sandstone rock, the uplifting of parts of it *en masse*, and the carrying away of fragments, are facts as patent as the presence of the erratic blocks themselves.

The Secretary of the Committee has had photographs of the section prepared, to be preserved with specimens of the erratic blocks found.

The Rev. W. Tuckwell has called the attention of the Committee to some very interesting boulders at Stockton, near Rugby, about equidistant from Leamington, Rugby, and Coventry. The dimensions of the largest boulder are 4 ft. × 2 ft. 4 in. × 2 ft. 2 in. It is in part angular, but some portions are rounded. One end is planed into two level slabs. No distinct striations can be traced. The direction of its longest axis is almost exactly N. and S. It is composed of granite from Mount Sorrel, Leicestershire. It is qnite isolated, and rests upon the lower middle lias clay. Its height above the sea is 289 feet. Through the

efforts of Mr. Tuckwell, measures have been taken for the preservation of this remarkable boulder. It has been moved from the roadside, where it was in great danger of being injured, placed upon a bed of concrete, and will be protected by railings.

A second boulder, also composed of Mount Sorrel granite, has been dug up from 5 feet below the surface in Nelson & Co.'s lime-works, half a mile to the N. of the boulder just described.

Its dimensions are 1 ft. 8 in. × 1 ft. 8 in. × 7 in.

In the same lime-works, and at about the same depth, a boulder of quartzite has also been found.

Its dimensions are 2 ft. 6 in. × 2 ft. 5 in. × 1 ft. 3 in.

Fragments similar to this last boulder have been found in considerable quantities; and from what the workmen say it appears that in past years many similar boulders have been discovered, and have been broken up in order that they might be got out of the quarrymen's way.

Leicestershire.—Mr. W. Jerome Harrison has sent the Committee the following note on a Leicestershire boulder which has travelled northwards:—

In the construction of the sewerage for the Clarendon Park Estate, near the Victoria Park, on the east side of the town of Leicester, some interesting sections of the drift were laid bare, which I examined in June 1880. Much of the drift exposed was of a loamy nature, containing erratics of moderately large size, and overlying, though with no well-marked line of demarcation between, the well-known great chalky boulder clay which spreads so widely in this district.

Among the travelled rocks contained in this deposit I particularly noticed one angular block identical in appearance with the syenitic rock which forms Enderby Knoll (4 miles south-west of Leicester), and Croft Hill (about 2 miles further in the same direction). These South Leicestershire syenites are well-characterised, and being somewhat abnormal their identification is easy.

The surface of the Clarendon Park Estate is about 300 feet above sea-level; while Enderby Knoll is about 350 feet, and Croft Hill 450 feet (these heights are approximations only). The block which I saw on the Clarendon Park Estate measured about $3\frac{1}{2} \times 2 \times 1\frac{1}{2}$ ft., and would weigh about three-quarters of a ton; it was irregular in shape and very angular. As it did not interfere with the direct line of the sewer it was not removed, but was covered in.[1]

Mr. J. Plant adds the following to his previous reports on the erratic blocks of this county:—

Boulder in the parish of Aylestone (Ord. Map, 63 S.E.), in a field opposite the third milestone S. of Aylestone. Its dimensions are 7 ft. × 6 ft. × 4 ft. About one-third of the boulder is buried in the ground. It is angular, and not known to have been moved by man. Longest axis, N.N.E. No striations are visible. It is granite from Mount Sorrel,

[1] The facts seem to the writer to show (1) that a submergence followed the retreat northwards of the great chalky boulder clay; (2), that when this submergence amounted to about 350 or 400 feet, the bosses of syenite which occur in South Leicestershire stood as little islands above the sea; (3), that 'coast ice' formed on the margins of these islands, on which blocks of rock, detached by the frost, fell; and (4), that a current running northwards carried at least one of these blocks down the Soar Valley and dropped it where it now lies, on the eastern brow of the Valley at Leicester.

distance 9 miles due north, and no rock like it occurs in same locality. It may be noted that it lies *due south* of the 'St. John's Stone' and the 'Holy Stone' mentioned in former reports, and would mark the line of the meridian. It is about 250 feet above the sea-level. A large photograph, 12 in. by 10 in., has been taken of it. It is connected with what are supposed to be 'middle glacial sands,' which appear to be the wreck of the 'Upper Keuper sandstone' (found *in situ* near them); these glacial sands being spread in long sheets, or ridges. It rests upon sandy drift. The weight of the boulder is about 10 tons.

At Beasley's Farm, Aylestone, is a group of boulders. The smallest is 1 ft. 9 in. × 1 ft. 3 in. × 10 in., and the largest 3 ft. × 1 ft. 9 in. × 1 ft. 3 in. They are subangular. Rocks of the same character as the boulders (which are for the most part coarse sandstones), occur at Garrat's Hill, 3 miles N.W. Some smaller blocks, composed of millstone grit, must have come 40 miles from the N.W. The group is about 250 feet above sea-level. About an acre is covered by the boulders. There are seven large blocks of sandstone within an area of about 20 square yards. They are found in upper boulder clay lying upon middle glacial sands. A large photograph, 12 in. by 10 in., has been taken of this sand quarry.

At the Clay-pit, Saffron Lane (Ord. Map, 63 N.E.), is a group of boulders. The smallest is 1 ft. cube, the longest 4 ft. × 3 ft. 6 in. × 2 ft. The following are the dimensions of fifteen: 4 ft. × 3 ft. 6 in. × 2 ft.; 4 ft. × 2 ft. 9 in. × 1 ft. 6 in.; 3 ft. 3 in. × 2 ft. × 1 ft.; 3 ft. × 2 ft. × 1 ft. 4 in.; 1 ft. 6 in. × 1 ft. × 10 in.; 1 ft. × 1 ft. 6 in. × 1 ft. 1 in.; 2 ft. 6 in. × 2 ft. × 1 ft.; 1 ft. 8 in. × 1 ft. × 1 ft.; 2 ft. × 1 ft. 4 in. × 1 ft.; 2 ft. × 1 ft. 8 in. × 1 ft.; 2 ft. × 1 ft. 8 in. × 1 ft.; 1 ft. 8 in. × 1 ft. 3 in. × 8 in.; 1 ft. 6 in. × 1 ft. × 1 ft.; 1 ft. 5 in. × 1 ft. × 6 in.; 2 ft. × 1 ft. 6 in. × 1 ft. They are rounded, angular, and subangular. Many of the smaller boulders are striated on *both sides*. They are derived from Mount Sorrel, Markfield, Hartshill, Ashby Coalfield, South Derbyshire, and places near Belvoir Castle. The distance from which these boulders have travelled ranges from 6 miles to 40 miles. Of the blocks counted and measured, thirteen are granite from Mount Sorrel of both the red and white variety. Of the remainder, one is a block of black basaltic-looking rock, which may have come from the Hartshill range, Warwickshire; the other is syenite from Markfield. The remaining twenty-two smaller blocks (not measured) are millstone grit, mountain limestone, chert, hard calcareous grits of the upper portion of the lower lias, and basaltic rocks. The group is about 230 feet above sea-level. The area opened is between 5 and 6 acres, and the boulders have gradually sunk to the bottom of the clay-pit, as the overlying 'drift' in which they are found was gradually removed so as to get at the marl underneath, and now they lie scattered over the pit. Thirty-seven have been counted, and fifteen of them measure as stated above. These blocks are found in middle sands and lower boulder clay, which vary from 6 to 10 feet in depth, and rest upon the Upper Keuper Marl. Two large photographs have been taken, showing some of these boulders lying upon the red marl floor, and the lower boulder clay upon the red marl.

On turnpike road opposite the New Gasworks, Aylestone (Ord. map, 63 N.E.) was found a group of three boulders. The smallest is 4 ft. × 3 ft. × 3 ft.; the largest 6 ft. × 3 ft. 6 in. × 3 ft. They are subangular. The large face of one of the boulders is ground smooth, and has a number of

striæ in various directions. They are derived from Markfield, 6 miles N.W. They are syenite, much decomposed by the decay of the felspar, and are about 210 ft. above the sea-level. They were found in making a sewer at a depth of about 4 ft. from the surface, resting upon the Upper Keuper Marl. As they stretched from side to side of the excavation the two large ones had to be blasted to get them out. The blocks have been removed to the Museum Grounds at Leicester.

At Knighton, on the estate of Clarendon Park (Ord. Map, 63 N.E.), is a group of boulders. The smallest is 1 ft. 6 in. × 1 ft. 6 in. × 1 ft.; the largest 2 ft. 6 in. × 2 ft. × 2 ft. They are rounded, angular, and subangular. Some of the lower lias blocks are polished, rounded, and striated on both sides. These striations are in various directions. The distances of the rocks from which they were derived are as follows: About 20 miles N.E. for the lias blocks; 6 miles N.W. for syenites and granites; 10 miles W. for greenstones. They consist of calcareous grits from the upper beds of lower lias; granites, syenites, and greenstones are in greatest number. The group is about 300 ft. above the sea-level. The boulders from this locality extend over nearly 100 acres of ground, and some of them have been described in former reports. They have been found in making streets and sewers and digging foundations of houses, lying in upper boulder clay and middle glacial sands.

In the parish of Thurnby (Ord. map, 63 N.E.) is a large collection of boulders. The smallest is a cube of 1 ft.; the largest 6 ft. × 2 ft. × 1 ft. 6 in. Many are rounded and subangular. The majority are scratched with shallow scratches on both sides of the longer face at various angles. They are derived from South Derbyshire, about 40 miles N.W. They are composed of mountain limestone, millstone grit, and permian rocks. The group is about 500 ft. above the sea-level. The greater portion of these boulders (of which there are many thousands under a cubic foot) were turned out in making a tunnel on a new line of railway from Leicester to Melton. An excavation was made in lower boulder clay, which including the tunnel extended about 3 miles. This lower boulder clay was found to be 80 ft. deep in the tunnel-shaft, and rested on the black shales of the middle portion of the lower lias. Boulders have been found in the adjoining villages, and have been described in former reports.

Shropshire.—The Committee have received from Mr. Luff a valuable report upon the group of erratic blocks found in the neighbourhood of Clun, Shropshire.

Professor Lapworth has examined a series of specimens, and describes them as Lower Llandovery grits and shales belonging to the Plinlimmon group of central Wales. The hills from which they have been derived are all south of Bala, and situated almost due west from their present position.

The following are the most remarkable among a large number of boulders. The '*Great Boundary Stone*,' marking the boundary of Clun and Treverward townships. It is on Rock Hill, 52° 24′ 28″ N.L.; 3° 3′ 40″ W.L., on the estate of Earl Powis. Its dimensions are 6 ft. × 6 ft. × 2·5 ft. No striations can be detected, but it is angular and polished on one face. It is a cleaved flagstone, and has travelled from a point south of Machynlleth. It rests upon a bed of clay and rubble above the Upper Ludlow rock. Height above the sea, 1,152 ft.

The '*Black Hill Boulder*,' 52° 24′ 40″ N.L.; 2° 59′ 50″ W.L.

This boulder may be calculated to contain from 8 to 10 cubic feet, and is subangular. It is a pebble grit belonging to the Plinlimmon group, and may have come, according to Professor Lapworth, from the neighbourhood of Rhaydr. So far as can be observed, it rests upon the same limit of bed as the Great Boundary Stone. Its elevation above the sea is 1,327 feet, and it is the highest of all the boulders of the group.

The '10 Feet Boulder.'—This boulder is a pebbly grit of the Plinlimmon group, and is very remarkable in many respects.

It lies on the Clun Hill, near Pen-y-wern, 52° 24′ 20″ N.L., 3° 0′ 30″ W.L., at an elevation of about 1,160 feet above the sea. It measures 10 ft. × 3 ft. × 3 ft., and weighs probably between 6 and 7 tons. It bears every evidence of having stood upright in the ground for a very long time. The base is tolerably angular and well-preserved, but the sides and apex are much weathered. About 4 ft. from the base it is deeply undercut, apparently all round, exactly as we should expect such a block to be where (on the ground-line) it had been most exposed to the combined influence of moisture and frost.

About 120 yards distant, at the highest point of the hill it stands on, is a clump of young firs. Old inhabitants remember, before the trees were planted, a circle of stones (foreign-looking boulders), some 30 yards in diameter, existed here. The farmers, finding this piece of ground useless for agricultural purposes, carted the refuse of their fields—loose stones and weeds—on to it, and afterwards the firs were planted. Distinct traces of the stone circle are still to be seen.[1]

The work of destruction among boulders is still going on with great rapidity. Many specimens are heard of as having existed some years ago, of which now no trace can be found. The Committee appeal, therefore, to observers in all parts of the country to assist them in completing the record upon which they are engaged.

[1] Mr. Luff sends the following memorandum on the Clun 10 Feet Boulder:—

'A line drawn from the centre of this circle to the base of the boulder, if prolonged, on one side would meet the point of lowest sunrise (December 21), and on the other that of latest sunset (June 21). This I have tested by mariner's compass, making careful allowance for variation of the needle, and higher elevation of the opposite hills, and also by observation of sunset on and about the longest day. The boulder lies on the S.E. side of the circle, and in my opinion has been used as a gnomon to indicate the point at which the sun would be first seen on the shortest day. A spot more favourable for the observation or worship of that luminary could hardly be imagined. It is the centre of an amphitheatre of hills, the valleys are out of sight, and nothing is in view but hill-top below, and the dome of heaven above.

'It is impossible to say who first erected this rude obelisk, or worshipped at this circle, but associated with them on the same range of hills are many clearly Neolithic remains, nicely polished flint arrow-heads, flint cores, and broken fragments.

'It is to be hoped this interesting stone may be preserved as a monument of a bygone age.'

Third Report of the Committee, consisting of Dr. H. C. SORBY, *and* Mr. G. R. VINE, *appointed for the purpose of reporting on Fossil Polyzoa (Jurassic Species—British Area only). Drawn up by* Mr. VINE (*Secretary*).

A PARTIAL examination of the Jurassic Polyzoa was made by Goldfuss,[1] but I am not aware whether he had any English examples of the types described and figured by him. With the exception of the *Aulopora* all the types are foreign, and I do not find any reference to British species in his text. In the 'Geological Manual' of De la Beche, published in 1832, a list of species is given, but only two are named as found within the British area—*Cellipora orbiculata*, Goldfuss (= *Berenicea*, Lamouroux), and *Millepora straminea*, Phill. In the 'Geology of York,' ed. 1835, Phillips gave three species only—*M. straminea*, *Cellaria Smithii*,[2] Scarborough, and an undescribed *Retepora* (?). When, in 1843, Professor Morris published his 'Catalogue of British Fossils,' there was a large increase of species, but many of these had not been thoroughly worked. In 1854, Jules Haime examined critically the whole of the Jurassic Polyzoa then known, and many English naturalists furnished him with material from their own cabinets so as to enable him to correlate British and foreign types. Lamouroux, Defranc, Milne-Edwards, Michelin, Blainville, and D'Orbigny have published descriptions of Jurassic species, and a list of these, so far as I am able, will be given at the end of this report. Professor D. Braun, by the publication of his paper on species found in the neighbourhood of Metz, added materially to our knowledge of French Jurassic types, and later foreign authors, Dumortier, Waagen and others, have increased the number of described species. Since the publication of Haime's work much valuable material has been accumulating in the cabinets of collectors, and I would willingly draw up a monograph if desired to do so. In the meantime I offer, in the following report, a rather compact analysis of genera and species known by name or otherwise to the palæontologist.

Classification.—Haime's arrangements of the Jurassic Polyzoa is very simple; all his species, excepting two, are placed in one family, the *Tubuliporidæ*. In the 'Crag Polyzoa,' 1859, Mr. Busk gave a synopsis of the 'Cyclostomata,' arranged in eight family groups, which were made to include several Mesozoic types. This arrangement, with a slight alteration, was followed by Smitt, Busk to some extent accepting the modification for the arrangement of recent Cyclostomata in his later work ('Brit. Mus. Cat.' pt. iii. 1875). The Rev. Thomas Hincks ('Brit. Marine Polyzoa,' 1880) disallows the family arrangement of Busk in so far as it relates to British species. The *Tubuliporidæ*, Hincks, include, in part, three of the families of Busk. In this report I shall follow Hincks as far as I am able to do so, as many of the Jurassic species may be included in the family *Tubuliporidæ* as now described. It will, however, in the present state of our knowledge at least, be im-

[1] *Petrifacta Germaniæ*, 1826–1833. [2] *Hippothoa* (?), Morris's Catalogue.

possible to arrange the species stratagraphically, as many, having the same type of cell, range from the Lias upwards. As far as I am able to do so I shall give the range of the species, beginning, of course, with the lowest strata.

Class Polyzoa.

Sub-order Cyclostomata, Busk.

Fam. I. Crisiidæ, Busk.

No fossils belonging to this family are at present known to have existed in the Jurassic epoch.

Fam. II. 1880. Tubuliporidæ,[1] Hincks.

'*Zoarium* entirely adherent, or more or less free and erect, multiform, often linear, or flabellate, or lobate, sometimes cylindrical. *Zoœcia* tubular, disposed in contiguous series or in single lines. *Oœcium*, an inflation of the surface of the zoarium at certain points, or a modified cell.' (Vol. i. p. 424.)

1. Stomatopora, Bronn.
2. Tubulipora, Lamarck.
3. Idmonea, Lamouroux.
4. Entalophora, Lamx.
5. Diastopora, „ (pars).

1825. Stomatopora, Bronn.

1821. *Alecto*, Lamx.; 1826, *Aulopora* (pars), Goldf.

I have already done partial justice to the uniserial *Stomatopora*, found in the Palæozoic rocks[2] of this and other countries. I have again studied the species described by James Hall, Professor Nicholson, and myself, and I cannot, at present, detect any generic character in the species that may be used by the systematic palæontologist to separate the Palæozoic from the Mæsozoic types. I must, therefore, regard the *Stomatoporæ* of the two epochs as one, though the sequence is broken in the Palæozoic—no species having as yet, I believe, been recorded from the Carboniferous series of this or any other country.

Jules Haime has already pointed out the striking differences between the *Alecto* of Lamx. founded upon *A. dichotoma* and the Devonian *Aulopora*; but I have not been able to verify his strictures regarding the exclusion of the latter from this group. It may be possible, however, to find that corals and polyzoa have been unwittingly united in some of our identifications. Haime gives seven different Jurassic species as found in the Lias and Oolite of this and other countries. As far as my material will justify the assumption, I claim for our British area the following characteristic types. As they are somewhat different I give the characters of our own species and varieties.

I. Stomatopora antiqua, Haime.

(pl. vi. fig. 7,[3] Jurassic Bryozoa).

Zoarium branching dichotomously, branches contorted, very rarely anastomosing. *Zoœcia* uniserial; lateral zoœcia given off from either

[1] For Synonyms see *British Marine Polyzoa.*

[2] *Brit. Assoc. Report*, 1881. Silurian Uniserial, *Stomatopora and Ascodictya.* 'Notes on the Wenlock Polyzoa,' *Quart. Journ. Geol. Soc.* Nov. 1881, Feb. 1882.

[3] The references to Haime's work, *Bryozoaires Fossiles de la Formation jurasse.*

the first or second cell of the branch, which in turn forms the base of a new branch; cells generally uniform in size, sometimes swelling towards the distal extremity; older cells slightly rugose, or granular; oral extremity raised at times with circular or semi-circular orifices; two cells average from three-quarters to one line in length.

Locality, &c.—Lower Mid. Lias, Fenny Compton, on *Gryphœa incurva.* Cabinet of Mr. Walford. (*Alecto dichotoma.* Beesley.)

Stomatopora dilatans montlivaltaformis (new variety). *Zoarium*, adherent, slightly ramified, consisting of short stem of uniserial zoœcia, which gradually widens so as to form dilated branches, but of very irregular form. *Zoœcia*, punctate, depressed; orifice circular, slightly raised; cells passing from uni- to tri-serial, and each cell measuring about half a line in length.

Locality.—Lower Mid. Lias, Cherrington.

Habitat.—On *Montlivaltia Victoria.*—Cab. Mr. Walford.

The peculiar habit and cell-character of this type is so distinct from the former, that, after many grave thoughts, I have decided to give it the above name. On the same coral are specimens of *Diastopora.*

STOMATOPORA WALTONI, J. Haime.

(pl. vi. fig. 3, Haime).

This species is found adherent to specimens of *Diastopora* from the Bradford clay, and also from the Cornbrash of Stanton. It assumes many peculiar habits, but the cell-arrangement generally is a rather constant feature. Sometimes it approaches the character of *S. dichotomoides*, D'Orb., at other times that of the recent *S. granulata*, M.-Ed. To the latter species Hincks[1] assigns a remote ancestry, and it is a difficult matter to say nay to his synonyms, and range in time, as all the uniserial *Stomatoporœ* may be closely related. My own specimens from the Greensand are too fragmentary to allow of a very close comparison.

Localities, &c.—Approaching *S. dichotomoides*, D'Orbigny's type, Great Oolite, Kidlington. Adherent to *Terebratula maxillata.* Cabinet of Miss Gatty. *S. Waltoni* type, Bradford Clay, and Cornbrash, Bradford and Stanton, Wilts. My own cabinet.

In our modern classification (Hincks) we have a sub-genus, *Proboscina*, which links together the genera *Stomatopora* and *Tubulipora.* Haime's second genus is also called *Proboscina*, but there seems to me to be a great difference between the recent and fossil species. The type of the recent sub-genus *Stomatopora incrassata*, Smitt, is a very peculiar species as regards the cells, and I know of no Jurassic type that can compare with it. The type of Haime's genus is the *Cellepora echinata*, Munster or Goldfuss. This latter species is a Tertiary type from Astrupp, and I fail to recognise any species in the British area that can compare with this either. Seeing that D'Orbigny applies the term *Proboscina* and *Idmonea* indifferently for certain species; that Busk places the sub-genus with his *Alecto*; and that Hincks practically disallows the division, it seems to me only a matter of very questionable convenience to retain it. There are, however, certain as yet undescribed types in both the Inferior and

[1] *Brit. Marine Polyzoa*, vol. i. p. 426.

Great Oolite that are really passage forms—evolutionary stages—which can neither be claimed as *Stomatopora* nor *Tubulipora*, and much less as *Diastopora*. With the exception of one species, I believe—the *P. Davidsoni*, Haime, from the Great Oolite of Hampton Cliffs—all the other types are from the foreign Jurassic areas. I cannot in my material recognise *P. Davidsoni*, but I have drawings of species lent to me from the cabinets of Mr. Longe (Inferior Oolite), Mr. Walford, and Miss Gatty (Great Oolite)—that one would naturally place in this genus. The one type, especially from Mr. Longe's cabinet from the Inferior Oolite of Cleave, near Cheltenham, in some of its characters approaches the *P. Jacquoti*, Haime, from the Inferior Oolite, Montveaux. There are other characters which would separate them widely. The same may be said of a very beautiful type in the cabinet of Mr. Walford, procured from the base of the Great Oolite. The species are adherent, as Haime describes, and meshes are formed by the inosculation of the branches, but the cell characters and arrangements appear now as *Stomatopora*, and anon as *Idmonea*; and I can well understand the confusion that was painful for Haime to note, when he says, 'The *Cellipora echinata*, Goldfuss, appears to me to be the first fossil known to be referred to the division (Proboscina). The others, principally those of the Crag, have been described as *Diastopora* or else as *Tubulipora*, either by Michelin or by Lonsdale. D'Orbigny has at first shown them under the name of *Idmonea*, and afterwards that of *Proboscina*, originally applied by Audouin in 1826. He criticises Milne-Edwards for having called *Criserpia* a species, which he, D'Orbigny, confounds with *Proboscina*.'[1]

The true *Idmonea* as an ERECT Jurassic type I do not know, though we meet with specimens partly adherent and partly erect in the cretaceous series. In the 'Catalogue of British Fossils,' Professor Morris gives *Idmonea triquetra*, Lamx., as found in the Great Oolite, Bradford, and Haime describes the same species in his text, and figures it (pl. vii. fig. 1, *a.b*). I notice the same *Idmonea* arrangement of cells as in many undescribed species of *Stomatopora* (?) at present lying dormant in the cabinets of collectors and students, and it is very difficult to conceive where these shall be placed in our modern classification, if we destroy the genus *Proboscina* as a passage group, or get rid of *Idmonea* other than as an erect type. Busk says 'Zoarium usually erect,' speaking of the fam. IDMONEIDÆ. Hincks, however, gives more latitude in his diagnosis of the genus *Idmonea*, for he says 'Zoarium erect and ramose, or (rarely) adnate.' Seeing that this latitude exists of partly adnate and partly erect types in the work of one of our greatest systematists, I strongly advise our local students to seek to throw light upon the origin of this unique type of Cyclostomatous Polyzoa. The *Idmonea triquetra* is at present unknown to me, and I can only point out the lines along which research can be made.

There is yet another type given by Haime to which I must direct particular attention. This is the *Terebellaria* of Lamouroux. I have been unable to refer to the original works for a description of the genus, but this has been done for me by George Busk, Esq., F.R.S., to whom I am indebted for the following very valuable particulars of the genus and species.

[1] Jules Haime, *Jurassic Bryozoa*, Genus *Proboscina*.

TEREBELLARIA, Lamouroux.

'A fossil, dendroid polypary, composed of cylindrical scattered branches, spirally twisted from left to right, or from right to left indifferently; pores prominent almost tubular, numerous, disposed quincuncially, and more or less inclined according to their position with the spires.'

Lamouroux says the genus should be placed after the *Millepores* and before the *Spiroporæ*, remarking 'that the *Spiroporæ* have the cells or the pores projecting as in *Terebellaria*, but that this character is observable only in well-preserved specimens. When the prominent part of the spire has been worn by attrition, it looks like a narrow riband wound round the branch.'

Two species are described by the author, *T. ramosissima* and *T. antilopa*, from the Terrain à polypes at Caen.

Hagenow's description is the same, but he includes in the genus *Ceriopora spiralis*, Goldfuss.

D'Orbigny adopts the genus of Lamouroux with the following character:—

'Colony entirely fixed by the base, whence spring thick cylindrical dichotomous branches, often very numerous, and forming a dendroid growth. Each branch presents three parallel spiral zones, which begin at the end of the branch in a projection formed exclusively of the germs of cells.' He enumerates four species—*T. gracilis*, D'Orb.; *T. antilopa*, Lamx.; *T. ramosissima*, Lamx.; and *T. tenuis*, D'Orb.

The peculiar habits of the species are remarkable. Haime says, 'The (colonial) development proceeds by layers of testules (cells), which superpose themselves by following a spiral line, and they increase afterwards downwards, covering themselves more and more.' In the figs. of pl. vi. typical features of the species are given, but the very peculiar spiral habit of *T. ramosissima* shown in transverse section, and the checked winding habit of *T. antilopa*, shown in longitudinal section, which will be further alluded to, may be seen in the figures of Lamouroux, of which Mr. Busk has furnished me with tracings.

The fossils which ordinarily pass for species of *Terebellaria* in the cabinets of collectors are a very curious group that may be more closely studied. My own studies are made from specimens from the Cornbrash, and Bradford Clay of Bradford and Stanton, Wilts, and it is from this locality that the School of Mines specimens were obtained.

To properly master the details of colonial growth, it will be necessary to isolate a single colony. The one furnished by Haime as a specimen of a young colony on stone shows a tapering proximal point, gradually widening by the addition of cells, till a certain fanlike shape is arrived at. A similar growth to this is found in young colonies of *Diastopora*. If superficially examined it will be seen that the cells are peculiarly arranged, beautifully punctured, with an orifice sometimes circular, at other times semi-circular, and sometimes the cell characters of portions of the colony bear a resemblance to *Bidiastopora ramosissima* of D'Orbigny. A complete and critical examination of the type will show that any fragment of stone or shell is sufficient to form the nucleus of a colony. It begins with a primary cell and then enlarges in a spiral direction, but to what extent the riband-like growth would be carried without a check

I am unable to say. In another direction a similar colony will be developed, the distal cells of which will ultimately meet and coalesce, both colonies striking out in fresh directions till met by another check, the growth not always being in an upward direction. The dendroid character of species is perfectly accidental.

With regard to the proper location of the type authorities differ. Professor Busk places it in the family *Idmonidæ*. In referring to *Heretopora* ('Crag Polyzoa,' p. 121) he says, 'Milne-Edwards, in his second edition of Lamarck, 1836, placed amongst the heterogeneous Polypiers foraminés, *Pustulopora*, *Chrysaora*, *Theonoa*, and *Terebellaria*.' Jules Haime places the genus immediately after *Idmonea* and before *Berenicea*, and it is near to, or, if need be, as a sub-genus of, *Diastopora* that I would be inclined to leave it. In accordance with this I think it will be best to redescribe the species.

TEREBELLARIA *ramosissima*, Lamx.

1816. *Millepora*, William Smith.—(Clay over Upper Oolite.)

Terebellaria.—(Of authors generally.)

Zoarium, a thin riband-like layer of cells encrusting foreign bodies, or coiling itself upon its own previously formed zoaria, ultimately assuming a spiral, ramose, dendroid or massive form. *Zoœcia* slightly elongated, sometimes disposed in spiral lines, rather more produced at the distal than at the proximal part of the cell; peristome thick, orifice circular, occasionally semi-circular, front of cell finely punctured. *Oœcia*, an enlarged globose cell, having beneath the orifice a semi-circular cluster of punctures definitely arranged.

Localities.—My own cabinet, Cornbrash, Stanton, Wilts; Forest Marble Box; Bradford Clay, Bradford, Wilts; Mr. Walford's cabinet, rich from several localities; School of Mines.

Genus DIASTOPORA, Lamx.

Sy. with *Berenicea* (pars), Lamx.

I am willing to accept this genus, in its wider sense, as defined by Hincks; yet I hardly think that it will be possible to include the whole of the foliaceous forms of the Jurassic period in one group. In this report I shall adhere to the arrangement of Busk, as I have done in my two papers on the Diastoporidæ, keeping the foliaceous types for distinct study. At the same time I am willing to admit that in getting rid of one difficulty in our grouping we open the door to admit others. Haime admits both the encrusting and foliaceous types; accepting the genus *Berenicea* for the encrusting, and *Diastopora* for simple-foliaceous and retiform species. Professor Braun, in his Jurassic studies, separates the species *Diastopora foliacea* from the group and establishes another, which he calls *Elea*, claiming for his type certain peculiarities which have been entirely overlooked by authors. It is very certain that the more closely we examine Jurassic Polyzoa and compare them with modern species of the genus *Diastopora*, the more divergent the types appear; and although we would rather accept a simple than an elaborate classification, still there are limits beyond which it is not wise to go.

The genus *Berenicea* was established by Lamouroux, and included in it, beside the fossil species, *B. diluviana* from the environs of Caen—two

living species. These, Haime says, he could not find in the Caen Museum; consequently they are not determinable by their figures alone. The *Zoarium* is adherent-encrusting, and formed of superimposed layers; the development commences in a simple manner, and is radiating or fanlike.

The *Diastopora* of Haime has a *Zoarium* with a large base, elevated, foliaceous or frondescent, sometimes reticulated, formed of ascendant leaves folding back upon themselves, and closely cemented in such a manner as to present often two shelving planes of cells. Then the planes are united by a *laminated calcareous epidermis.*[1]

Diastopora foliacea, of Lamx., covers two distinct types. One has been well worked out by Professor Braun,[2] and upon this he seeks to establish the family Operculata, order Eleina, naming his type *Elea foliacea.* The other species Milne-Edwards named *D. Lamourouxi*; and it forms with *D. Waltoni*, Haime, the Diastopora simples of Edwards. The next section of Haime and Edwards includes the whole of the Biserial species. For these Blainville, in 1830, or rather for a section of the now recognised species, founded the genus *Mesenteripora*, still retained by Busk in the Crag Polyzoa and Cyclostomata,[3] and in his list of Polyzoa collected by Captain H. W. Fielden ('Jour. of Linnæan Soc.' 1880), and also by Mr. Waters. Blainville's genus is again rechristened by D'Orbigny, and becomes *Bidiastopora*; establishing for the *D. lamellosa* a special genus which he calls *Latero-multelea.*

Genus DIASTOPORA, Lamouroux.

Sy. with *Berenicea* (pars), Lamx., 'Expos. Meth.' 1821.

Haime figures and describes five species of *Berenicea* and fourteen *Diastopora* as present in the Jurassic series. I shall only notice those species which are found in the British area.

I have already, in a previous paper,[4] drawn attention to four types of *Diastopora* (*Berenicea*, Haime), not previously noticed by authors. They are

1. *D. stomatoporides*, Vine.	3. *D. oolitica*, Vine.
2. *D. ventricosa* ,,	4. *D. cricopora* ,,

These species range from the Lias to the Great Oolite; and for particulars, details, and description I refer the reader to the paper itself.

Before leaving this purely descriptive part, I wish to speak of a paper 'On the Relation of the Escharoid Forms of Oolitic Polyzoa,' by Francis D. Longe, F.G.S.[5] In this paper Mr. Longe very ably discusses certain peculiarities of cell-character, showing their apparent relationship to the Escharoid forms of the Cheilostomata; especially drawing the attention of the palæontologist to the opercula of the Oolite species.

There are many discrepancies in our modern classification of the Polyzoa; and Mr. Longe has, by the publication of this paper, increased our knowledge of their number. Seeing that the whole of the remarks are founded upon facts gleaned from a comparative study of Oolitic specimens, we cannot do more than accept the hints and illustrations, and work them into our future histories rather than ignore them altogether.

[1] Italics mine.
[2] *Die Bryozoa des Mittleren Jura*, 1879. [3] *Brit. Mus. Cat.* pt. iii.
[4] Further notes on the family *Diastoporidæ*, Busk, *Quart. Jour. Geo. Soc.* August 1881.
[5] *Geological Magazine*, January 1881.

I cannot, however, see my way clearly at present to accept without a demur his conclusions. As a 'suggestive sketch of the genealogical arrangement of certain families,' Mr. Longe offers the following :—

'Race DIASTOPORIDÆ.

'Families or genera represented in the Oolites :—

'Creeping.—*Diastopora.*

'Foliaceous.—*Bidiastopora, Mesenteripora, Elea, Eschara.*

'Dendroid.—*Cricopora, Melicertites, Entalophora.*'

The remaining portion refers to species found in the Chalk and subsequent periods.

DIASTOPORA DILUVIANA.

Berenicea diluviana, Lamx. *B. diluviana*, Haime.
Berenicea diluv., or *Diastopora diluv.* of authors generally.
Repto-multisparsa diluv., D'Orb.

This species is present in the Inferior and also in the Great Oolite, and the name should be restricted to the thin, papyraceous specimens which encrust, with varying habits, stones and shells. The *Zoarium*, in its youngest stage, begins with a primary cell, which gradually increases in size till a small fanlike outline is reached, some of the cells turning to the right, others to the left of the primary one. After this the *Zoarium* is of varying habit, and all the cells are deeply immersed, and specimens appear like a continuous cœniceum, very much punctured, the peristomes only rising but very slightly above the surface. The cells are distinct, in very sheltered parts of the *Zoarium* the distal portion of the tube much produced.

Localities.—Inferior Oolite abundant at Cleave, near Cheltenham. Cabinets of Mr. Longe and my own.

DIASTOPORA MICROSTOMA, Michelin.

Berenicea microstoma, Haime, pl. vii. fig. 3, *a.d.*
„ *undulata*, D'Orb. (Pal.), France.
Repto-multisparsa microstoma, D'Orb.

I feel certain that this species, though much smaller in the cells, has at times been identified with the one above. It is only on very rare occasions that the two could be possibly confounded. The most distinguishing features of this species are the proliferous habits and the smallness of the cells. Some of the cells, too, appear like those of *Diastopora Lucensis.*

Localities.—Abundant in the Great Oolite, generally encrusting species of *Terebratula.* The cabinet of Mr. Walford very rich. Haime gives Hampton Cliffs as one of the localities from which he obtained his specimens.

I wish to draw particular attention to this species on account of its peculiar proliferous habits. Many of the fresh colonies originate from some of the marginal cells of the older colony. They begin with a primary cell as ordinary *Diastopora*, and the *zoarium* very soon assumes a fanlike, then a circular, habit. Newer colonies also cover the older ones, and the innumerable growths give a very thick appearance to the blended *Zoaria.*

Another British species is given by Haime:—

Diastopora Lucensis (Berenicea, pl. vii. fig. 4, *a.c*).
= „ *diluviana*, Milne-Ed.
= *Multisparsa Luceana*, D'Orb.

Localities.—Hampton Cliffs, Walton; Bradford Clay and Cornbrash, Laycock.

II. Biserial Diastopora, Milne-Ed.

Mesenteripora, Blainville; Bidiastopora, D'Orb.; Ditaxia, Hagenow.

It is well that the encrusting and biserial *Diastopora* should be separated, but not widely so. In the choice of the above names I have selected the simplest—*Diastopores biserialaires* of Milne-Edwards—because it has the precedence of the *Bidiastopora* of D'Orb. Busk—in the 'Crag Polyzoa' and in the 'Brit. Mus. Cat.' pt. iii.—has chosen Blainville's name for this division of the group.

My chief objection to Blainville's term for the biserial species may be found in the diagnosis as given by Busk: 'Cells in two layers, parted by a calcareous septum.' In all the specimens figured in 'Crag Polyzoa'[1] of *Mesenteripora meandrina* the transverse sections of the foliaceous zoarium are shown to have this septum very distinct. In many of Haïme's figures where cross sections are given, the septa are also shown to be present. It seems to me, judging from the foliaceous specimens in my own cabinet, that this 'calcareous septum' is only an apparent, and not a real character. If sections are made in a line with the cells, the only axis visible is that made by sections of the cell-walls. In a cross section of the foliations there is an apparent septal division, but the more closely this is examined the less real will it be. The septal divisions of *D. scobinula*, *D. Terquemi*, and *D. cervicornis*, as given by Haime, show one, two, and three sections of cells on either side of the septal line; and specimens of Inferior Oolite species found in the neighbourhood of Cheltenham are in many respects of a similar character. As I have been able to examine only a very limited number of species, I should be glad to have more detailed information if students of our Oolitic Polyzoa will address their attention to this point. Meanwhile, by selecting the divisional name of Milne-Edwards I shall not commit myself to any generic name dependent upon a questionable structural character.

Jules Haime, after very careful working, saw reason for establishing fourteen species of biserial *Diastopora*, the whole of which are not found in the same horizon in either this or other countries. Leaving *D. foliacea* and *D. Lamourouxii* we have nine foliaceous species as common to the Jurassic Fauna generally. Some of these range from the Inferior to the Great Oolite and the Cornbrash; whilst others, so far as observation at present favours us, are confined to one horizon only. Two species given by Haime—*D. Michelini*, Blainville, and *D. Eudesana*—range from the Inferior Oolite through the Great Oolite; and, according to Busk, is possibly identical with the *Mesenteripora meandrina* found amongst the Crag Polyzoa, and in recent Arctic fauna. I cannot assert positively that the species are identical, or that we ought to accept all the synonyms of Busk: still there is great probability in their favour; but the fragments of Busk will bear no comparison in point of size with the fine

[1] Plates xvii. fig. 2; xviii. fig. 4; and xx. fig. 2, pp. 109, 110.

specimens from the Jurassic formations in the cabinet of Mr. Longe. The cells are very similar in character, both in their worn and in their perfect state.

Two other species—*D. Wrighti* (*D. foliacea* of Mor. Catalogue), and *D. Mettensis*—are both Inferior Oolite types; the first ranging from the Inferior to the Great Oolite in this country. The *D. Wrighti* also may be the *Bidiastopora* and *Mesenteripora meandrina* of D'Orb. Mr. Longe—who has made careful observations on the species—has selected for illustration the most typical features of cell arrangement and character of the two types; and Dr. Woodward, in the beautiful plate which illustrates Mr. Longe's paper on the 'Escharoid Forms of Oolitic Polyzoa,'[1] has done ample justice to the selection. A comparison of the two types of cell in figs. 2 and 3 of that plate will give special details of structure sufficient to justify Haime in their separation as species. It must not be supposed, however, that the character and arrangement of the cells are always so clearly defined as in the plate. The cells vary very much, and it may be possible to find similarly shaped cells to these in other species of the Oolitic *Diastopora*.

Haime gives us another type of *Diastopora* cell as found in a species in the Inferior Oolite of this country, and also in the Great Oolite of Ranville and Caen. In the plate already referred to (fig. 4) Mr. Longe has selected for typical illustration a specimen from Caen. Haime calls it *D. lamellosa*, Mich., and gives as its synonyms *Elea*, *Multelea* and *Lateromultelea Ranvilliana*, D'Orb. and *Eschara Ranvilliana*[2] of Michelin. Relying upon the evidence of Mr. Longe, I cannot help but select his opinion on this type. Speaking of the illustration, pl. 11, fig. 4, 'Geo. Mag.' Jan. 1881, he says, 'I have little doubt but that this form is the *Eschara Ranvilliana* of Michelin. In his figure the areolation is slightly more angular than in the part shown in (my) figure. Jules Haime has classed a somewhat similar form as *D. lamellosa*. D'Orbigny's *Eschara* or *Elea triangularis* is evidently a very similar form.'[3] The type of cell I am not familiar with as a British species.

In the *Diastopora Waltoni*, Haime, and in the *D. Davidsoni*, Haime, one from the Inferior Oolite near Cheltenham and the other from the Great Oolite Hampton Cliffs, we have types of cells far from being unique. The same may be said of the cells of *D. Eudesana*, Haime, also a Great Oolite type. The same peculiarity of cell structure and arrangement may be found in some of the adherent or encrusting *Diastopora*, as in the more richly developed foliaceous species, but whether the foliaceous species as a whole are developed from the encrusting forms I am unable to say. In all probability they may have been so, and this would justify the Rev. T. Hincks in breaking up the artificial divisions and classifying the foliaceous and the encrusting species under one generic term.

In the *D. cervicornis*,[4] Michelin, of which species the *Bidiastopora* and *Elea cervicornis* of D'Orb. are synonyms, we have very insufficient data to deal with. It is said to occur both in the Great Oolite of Ranville, and in the Bradford Clay of Pound Hill. I am not acquainted with the species as a British type.

[1] *Geological Magazine*, January 1881.
[2] A beautiful illustration of this type is given in Nicholson's *Palæontology*, vol. i. p. 420, fig. 270.
[3] *Geo. Mag.*, January 1881, pp. 33, 34; descriptive text of fig. 4.
[4] For illustration, see Nicholson's *Palæontology*, vol. i. p. 431, fig. 272.

Many valuable foliaceous types are in the cabinet of Mr. Longe, and a few are in the Museum of the School of Mines, and in the Cambridge Museum. Some few of Mr. Longe's specimens I have been allowed to examine, and I have five species in my own cabinet. These I have examined both in the mass and in sections before drawing up the details furnished in this report. It is high time that a monograph of British Jurassic Polyzoa should be undertaken by some competent authority before the masses of material at present in the hands of private collectors are again scattered, as previous collections have been, without note or comment. Besides my own specimens I have examined many in the cabinets of Mr. Walford and his friends. If these could be compared with the type specimens named by Haime, a more valuable addition to Palæontology could be made than we at present possess. In the work of Professor Phillips, 'Geology of the Valley of the Thames, 1871,' it is painful to read his remarks on the Polyzoa of the various formations laid bare in the valley. Speaking of Liassic Polyzoa, he says, 'specimens have been observed at Fenny Compton.' Of the Inferior Oolite, 'Insufficiently examined in the series.' In the Great Oolite only four species are given —*Alecto dichotoma*; *Cricopora straminea*, Phill.; *Diastopora diluviana*, and *Terebellaria ramosissima*.

Of the Oxford Oolitic Period, Phillips says, 'The rarity of Polyzoa in the Oxford Oolites and Clays is somewhat remarkable, and appears to be in some way related to the even more remarkable rarity of Brachiopoda, on whose shells in the Bath Oolites so many of these beautiful objects are found.'[1] In the Cretaceous system (p. 434), a list of nearly fifty species of Polyzoa is given by the author as occurring in the valley of the Thames.

I have before me a very valuable series of notes compiled by Mr. Walford, on species of Polyzoa found in his own neighbourhood. If other students would undertake to furnish notes of a similar character of other localities, a compilation of the range of types would be easily made. As it is we have insufficient data and ill-digested identifications to deal with.

1821. Genus Spiropora, Lamouroux.

1822. Intricaria, Defranc. 1830. Cricopora, Blainville. 1840. Meliceritites, Roemer. 1850. Entalophora, D'Orbigny. 1853. Cricopora, Spiropora, Tubigera, Meliceritites, Laterotubigera, Entalophora, D'Orb. Palæontology.

I have already vindicated by use and preference the retention of this genus for species of Palæozoic Polyzoa.[2] I still retain the name for species of the genus very common in the Mesozoic rocks. I have also given the synonyms with their dates of genera intended to supersede Lamouroux's original term. It may be as well to define and limit the genus as applicable for the reception of Palæozoic, Mesozoic, and Cainozoic species. I am not aware that any recent species of Polyzoa can be included in the group.

'*Zoarium* dendroid with dichotomous branches. *Zoœcia* elongated, closely connected laterally, but less distinct at the base, perforated with very small and round pores . . . Peristomes circular, more or less pro-

[1] Pp. 123, 239, 302.

[2] 'Notes on the Wenlock Polyzoa,' *Quart. Jour. of Geo. Soc.* February 1882, pp. 43–68.

jecting, forming at the surface of the branches circles which ordinarily are not complete, and each of them constitutes one of the turns of a spire many times interrupted. These rings appear more regular when they are distant from each other; when they are crowded they are often difficult to recognise.'[1]

SPIROPORA LIASSICA, Tate. 'Geological Magazine,' 1875.

This species has been very well described by Professor Tate in the above magazine. I have seen the type specimen, which is in the Museum of Practical Geology. But my own specimens, given to me by Mr. Walford, are different from the types of Tate. The zoarium is more flattened and the cells are longer and more irregular. The type of cell approaches nearer to that of *Diastopora stomatoporides*, Vine ('Jour. of Geol. Soc.' August, 1881), than that of ordinary *Spiropora*.

Localities.—Leptena beds of Moy., King's Sutton. *Amm. spinatus* beds (Beesley).

Haime admits eight accredited species, but only three are present in our British area. *S. straminea*, Phill.; *S. cæspitosa*; and *S. Bajocensis*.

SPIROPORA STRAMINEA.

Millepora straminea, Phill., 'Geo. of York,' pl. ix. fig. 1.

This species as figured and described by Phillips in the above work is that ordinarily met with in fragments. The *zoarium* is dendroid, variously branched, branches anastomosing so as to form an intricate amalgamation of branches, all of which are of the ordinary size. *Zoœcia* tubular, arranged in series spirally, peristomes circular, slightly raised.

This species is widely distributed, ranging from the Lower Oolite to the Greensand, and on account of the very peculiar habit of the amalgamation of the branches it received from Defranc the name of *Intricaria*. Blainville gave two species the name of *Cricopora*, because the cells are arranged in rings. This is the character of *Ceriopora verticillata*, Goldfuss, which is given as a synonym of the species by Professor Braun. It has also received the name of *Latero-tubigera* from D'Orb., but Professor Braun prefers to adopt the generic name of *Entalophora* for the two species described by him as found in the middle Jura of the neighbourhood of Metz.

Localities.—Inf. Oolite, Peagrit, Cheltenham. Great Oolite, Scarborough, Phillips, 'rare in this stratum.'

SPIROPORA CÆSPITOSA, Lamouroux.

Cricopora, Blainville. *Entalophora*, Professor Braun.

This species is distinguished by much thinner and more slender branches. The spiral arrangement of the cells is somewhat similar, but the tufted character is a distinguishing feature.

Localities.—Inferior Oolite, Base of Oolitic Marl., Nutgrove station. Morris cites Hampton and Bradford.

[1] Haime's *Jurassic Bryozoa*. One passage has been left out respecting 'transverse diaphragms,' which I have not been able to verify.

ENTALOPHORA CELLAROIDES, Lamx. (*Pustulopora*, Nicholson.)
Plate ix. fig. 8, *a. b.* Haime's 'Jurassic Bryozoa.'

This species is described by Haime as above. It is very different from any of the *Spiropora* described by him, and he says that an 'incomplete example was furnished to him by Walton, procured from Hampton Cliff.' I am not acquainted with the type.

Judging from the figures given by Nicholson (p. 430, 'Palæontology,' vol. i.), this is a true *Entalophora*, well deserving of separate recognition. Under any circumstances it could not be confounded with *Spiropora*.

Fam. III. HORNERIDÆ. Hincks.

This family contains only one genus, *Hornera*. There is no representative of the family, in Brit. Jurassic Rocks at least, and I am not aware of any recorded species of the genus in Foreign Oolites. As the Rev. Thomas Hincks says that 'the genus HORNERA is connected with TUBULIPORIDÆ, through *Idmonea*,' to which it bears in many points a very close resemblance,[1] in all probability early types of the genus, as defined by him, may yet be found in either the Jurassic or Cretaceous rocks. The *Siphodictyum*, of Lonsdale, is given as one of the synonyms of Hornera.[2]

Fam. IV. LICHENOPORIDÆ.

This is the last family given by Hincks in which Jurassic Polyzoa can be placed. The genus *Lichenopora* of Defranc has also a number of synonyms, but as species of the genus are rare in the Oolites, we find only one recorded. Haime says the genus has not been represented until now, other than by Tertiary or Cretaceous fossils. In *Lichenopora Phillipsii*, derived from the Great Oolite of Hampton Cliff, the *zoarium* is disciform, very slightly elevated, and adherent only by the middle of its inferior face. The upper surface resembles a fungus, with unequally developed rays formed of a series of long zoœcia, ordinarily doubled. The peristomes are polygonal, regular, and closely connected.

Species of the genus, in all probability the same as above described, are found in the Inferior Oolite, but too indistinct for description.

Another peculiar genus of Lamouroux's is accepted by Haime—*Apsendesia*—in which to place two species of Jurassic Polyzoa. In his synoptical arrangement of the Polyzoa Cyclostomata, Busk places this genus in the family THEONOIDÆ: '*Zoarium* massive sub-globose, or irregular; *zoœcia* contiguous crowded.' Haime describes in the foreign Oolites two species—*A. cristata*, Lamx., and *A. clypeata*, Lamx. I have no means of studying these, but Professor Braun, in his paper, places as the synonyms of *Apsendesia*—*Defrancia* and *Pelagia*. In his description of the *Fascicularia* of the Crag—one of the genera of THEONOIDÆ—Mr. Busk places *Apsendesia* (pars), Blainville; questioning its affinity with Lamouroux's type, as one of the synonyms of the *Fascicularia* of Milne-Edwards. Facially the specimens of *Lichenopora* found in our own Oolites may bear some resemblance to the figures of Haime, but as there was some confusion in the mind of Blainville when drawing up the characters of the genus *Apsendesia*, the student will do well to refer to the 'Crag

[1] *Brit. Marine Polyzoa*, vol. i. p. 467. [2] *Ibid.*

Polyzoa' (p. 139) for a description of *Fascicularia*, as given by Busk, and its relationship to *Apsendesia cristata*, Lamx.

Since the above was written, Mr. Walford has kindly furnished me with the following note on this genus, and of species in his own cabinet.

'*Apsendesia cristata*, Lamx. The Barford, Oxon, specimen agrees fairly with Haime's description, excepting that it seems to be attached not by a central base, but to be adherent by its whole breadth. It seems to be more regular than most of the forms figured.

'*Locality.*—On the inside of shells; Inferior Oolite.

'*Apsendesia*, sp. The fasciculæ are rather coarser, slightly sinuous, and less numerous than in the species mentioned above.

'*Locality.*—On stones; Inferior Oolite; Stowe-on-the-Wold.'[1]

There are still several genera described by Haime which, on account of their rarity, have not been so closely studied. One of these—*Fasciculipora*, a genus of the family FRONDIPORIDA, Busk—has assigned to it a species *F. Waltoni*, Haime. It is found in the Great Oolite at Hampton Cliff. This genus is still represented by at least two species in the Australian and South Patagonian Seas. In the Crag Polyzoa three species are described under the generic term of *Fungella*, Hagenow, in the family CERIOPORIDA, Busk.

Theonoa, Lamx., is represented by three species, one of which—*T. Bowerbankii*, Haime—is found in the Inferior Oolite of Cheltenham, both by Bowerbank and by Walton.

The genus *Constellaria* was founded by Dana, and is probably synonymous with *Stellipora*, Hall, and *Radiopora*, D'Orb. I am not acquainted with the type in our English Oolites. The only example known—*C. Terquemi*, Haime—was discovered in the Infra Oolite (Metz) by M. O. Terqueim. The *zoarium* is encrusting, with short *zoœcia*, erect, prismatic, slightly unequal in width, of two kinds: the one more erect, disposed in a double or triple or radiating series; the other very short, occupying the interval of the rays. Two recent species of *Radiopora*, D'Orb., are given by Busk, and one—*R. cristata*—in some respects answers to the description of the Oolitic species as given by Haime. *Radiopora* is placed in the CYCLOSTOMATA, pp. 34–35, with the Discoporellida. In placing the *C. Terquemi* in the genus *Constellaria*, Haime says, 'I do not find any essential difference between the Palæozoic Fossils and those of the secondary period, which D'Orbigny calls *Radiopora*, and they are bound, without doubt, to form one and the same genus.'[2]

The genus *Chilipora* is one of the *Heteroporida* types, and it, too, is founded upon a single unique example. There are, however, characters about the peristome and also the interjacent openings of *C. guernoni*, Haime, altogether at variance with the known types of British *Heteropora*. The specimen was found at Ranville, in the Great Oolite.

1835. Neuropora, Bronn.

Chrysaora, Lamx. *Filicaria*, D'Orb.

Species belonging to this genus are present in our British Oolites, in the Bradford Clay, and Cornbrash, but I have not been able to secure specimens to operate upon so as to study the internal characters. Dumortier describes several species from the Middle Lias, Haime describes three from the Great Oolite of Ranville and Hampton Cliffs, and

[1] Letter, June 1, 1882. [2] *Jurassic Bryozoa*, p. 206.

Professor Braun says that it extends from the Lower Lias onward into the White Jura and also into the Great Oolite of Ranville. It is also found about Metz. Through the kindness of Professor Roemer of Breslau I have had supplied to me the species of *Ceripora*, Goldfuss, which are referable to this genus, but the types differ in many particulars from our own species.

One peculiar type is separated from the genus *Neuropora* by Haime, and is made the Oolitic type of the genus *Acanthopora*, D'Orb. It is the *Chrysaora spinosa* of Michelin. A specimen of the genus *Semycitis*—another *Chrysaora* type—was found by Walton at Bath. The British species of Neuropora and allies are—

Neuropora spinosa, Lamx. = *Chrysaora spinosa*.
,, *dumicornis* ,, = ,, *dumicornis*.
and *Ceriopora angulosa*, Quen.
,, *Defrancii*, Haime.

1834. Heteropora, Blainville.

We have now left one group of Oolitic Fossils which within the last few years have been more closely studied than any of the others, because of their supposed relationship with the Palæozoic *Monticulipora*.

In his 'Petrifactions of Germany,' Goldfuss placed in the genus *Ceriopora* three species, which he describes and figures[1] as containing large and small openings on the surface of the branches. These were *Ceriopora anomalopora*, *C. cryptopora*, and *C. dichotoma*, all of which were from the Mastricht beds of Astrupp or Nantes. In 1834 M. de Blainville separated these from the *Ceriopora* of Goldfuss, and established another one for their reception which he called *Heteropora*, assigning as essential structures the two sorts of openings, but giving very few details respecting the genus. After this Milne-Edwards added to them *Millepora dumitosa* and *corigera*, Lamouroux. In his 'Miocene Fossils of North America,'[2] Mr. Lonsdale complained of the inadequate description of Blainville as not having in it sufficient details 'to enable an opinion to be formed of its complete characters, or of the nature of the minor openings.' This error was to some extent rectified by Lonsdale, and we owe to him the merit of being the first author who clearly indicated upon sufficient grounds the real zoological position of the genus. Jules Haime, in his 'Jurassic Bryozoa' (pp. 207–8), redescribes the genus, and as his diagnosis has particular reference to Oolitic types, I reproduce a portion of his description.

'*Zoarium* of variable form, but chiefly dendroid.

'*Zoœcia* apparently united by some lamellar prolongation of the walls, whence result some intermediary tubes, the terminal aperture of which has been closed by a thin calcareous pellicle, but which perhaps were themselves intended to become young cells. When externally examined two different sets of openings are seen, varying in size, sometimes circular, at other times polygonal. . . . There are fundamental differences between the peristomes of the true cells and those of the intermediary openings; still, the matter of the young cells is very uncertain, and is not of any specific value (?).'

In accordance with this decision, Haime admitted only two species—*Heteropora conifera* and *H. pustulosa*—where Michelin admits seven, and D'Orbigny eight.

[1] *Petrifactions*, pl. x. fig. 1–5, fig. 3, fig. 9, &c.
[2] *Quart. Jour. Geo. Soc.* vol. i. p. 500 (1845).

BRITISH AREA

	Genus and Species	Author	Lias	Inf. Oolite	Gt. Oolite	Cornbrsh.	Oxford Cl.	Coral Reg.	Germany	France
	II. TUBULIPORIDA.		1	2	3	4	5	6	7	8
	STOMATOPORA, Broun.									
1	*Antiqua* . . .	J. Haime . .	* H.						*	*
	dilatans . . .									
2	Var. *montlivaltiformis* .	New var. . .	* W.							
3	*Waltoni* . . .	J. Haime . .			*	* B.				*
4	*dichotoma* . . .	Lamx. . . .		*		* B.				
5	*dichotomoides* . .	D'Orb. . . .								*
6	*Bouchardi* . . .	Haime . . .					*			*
7	*Terquemi* . . .	,, . . .								I. O.
8	*Desoudini* . . .	,, . . .								I. O.
	PROBOSCINA, Sub-genus									
9	*Eudesi* . . .	,, . . .								
10	*Davidsoni* . . .	,, . . .			*					
11	*Buchi* . . .	,, . . .								Ran.
12	*Alfredi* . . .	,, . . .								I. O.
13	*Jacquoti* . . .			*						I. O.
14	III. IDMONEA—*triquetra* .	Lamx. . . .			*					Ran.
	DIASTOPORA (adherent) .									
15	*Liassica* . . .	Quendst . .							L	
16	*Crassolensis* . .	Dumortier . .								Inf. L.
17	*stomatoporides* . .	Vine (type) . .	*							
18	*diluviana* . . .	Lamx. . . .		*	* H.	* H.				Ran.
19	*microstoma* . . .	Michelin . . .			*					
20	*striata* . . .	Haime . . .								
21	*Lucensis* . . .	,, . . .			* H.	* H.				
22	*Archiaca* . . .	,, . . .								* H.
23	*ventricosa* . . .	Vine . . .		*	*					
24	*Oolitica* . . .	,, . . .		*	*					
25	*cricopora* . . .	,, . . .		*	*					
	DIASTOPORA (Biserial)									
26	*Lamourouxi* . .	Haime . . .								Ran.
27	*Waltoni* . . .	,, . . .		*						
28	*foliacea* . . .	Milne-Ed. & H. .		* H.	* H.					Ran.
29	*Eudesana* . . .	,, ,, . .			* H.					
30	*Davidsoni* . . .	Haime . . .			* H.					
31	*Wrighti* . . .	,, . . .		*	* H.					
32	*scobinula* . . .	Michelin . . .		* H.	* H.					* 2
33	*Terquemi* . . .	Haime . . .								* 2
34	*Michelini* . . .	Blainville . .		*						* 2.3
35	*lamellosa* . . .	,, . . .		* H.	*					* 3

36	*cervicornis*	Michelin				* H.				
37	*ramosissima*	D'Orb.								* 3
38	*Mettensis*	Haime		*						* 2
39	*verrucosa*	Ed. (Mor. Cat.)			*					
	SPIROPORA									
40	*elegans*	Lamx.								* 3
41	*straminea*	Phillips		*	*	* W.				
42	*abbreviata*	Blainville								
43	*tessonis*	Michelin			* M.					* 3
44	*Liassica*	Tate	*							
45	*cæspitosa*	Lamx.		* ?	*	* M.				* 2.3
46	*Bajocensis*	D'Orb.		*	*					* 2.3
47	*compressa*	Haime		*						
48	ENTALOPHORA, Lamx. *cellariodes*	Lamx.			* H. ?					
	IV. LICHENOPORIDÆ, Hincks									
	LICHENOPORA, Defranc.									
49	*Phillipsii*	Haime		*						
50	CONSTELLARIA (Dana)—*Terquemi*	"								* 2
	V. CERIOPORIDÆ, Busk									
	HETEROPORA.									
51	*conifera*	Lamx			*					* 2.3
52	*pustulosa*	Michelin		*	*					
53	*reticulata*	Haime								
54	CHILOPORA—*Guernoni*	"								
	NEUROPORA, Broun.									
55	*spinosa*	Lamx			* H.	* H.				
56	*dumicornis*	"			* H.	* H.				
57	*Defrancei*	Haime			* H.					
58	*mamillata*	Fromantal								
59	*striata*	Goldf.								Inf. L.
60	*angulosa*	"							* 6	
61	FASCICULIPORA—*Waltoni*	Haime			* H.				* 6	
	VI. THEONOIDÆ, Busk.									
	THEONOA, Lamx.									
62	*chlatrata*	Lamx								
63	*distorta*	"								
64	*Bowerbanki*	Haime		*						
	APSENDESIA, Lamx.									
65	*cristata*	Lamx		* W.						
66	*clypeata*	"		* W.						

* Lias of Valliers Terquem

In his classical 'Monograph of the Fossil Polyzoa of the Crag' (1859), Professor Busk very much simplifies the diagnosis of Haime, because, as I think, the types of the 'Crag' were more suitable for this purpose than those of the Cretaceous or Oolitic periods.

'*Zoarium* erect, cylindrical, undivided or branched; surface even, furnished with openings of two kinds: the larger representing the *orifices* of the cells, and the smaller the *ostioles* of the interstitial canals or tubes.' 'Crag Polyzoa,' p. 120.

Since this was written species of recent Heteropora have been discovered and described by A. W. Waters, F.G.S.,[1] from the neighbourhood of Japan, and by Professor Busk from the neighbourhood of New Zealand,[2] and a critical study of these species has thrown some little light upon particular structures in the Oolitic types. I fail, however, to detect, either in the descriptions of the recent, or in my own investigations of the ancient type, any evidence, or characters, that would be sufficient to establish a link between *Monticulipora* and *Heteropora*, or, in other words, between Tabulate Corals (which have intercellular openings like *Heteropora*) and Polyzoa. Yet it is very strange that in the Mesozoic epoch we should have well-developed types like *Heteropora* which we are content to call Polyzoa, and yet be unable to associate them with Palæozoic species having similar *external* characters. But it is so, and without seeking to do violence to structural evidence we must wait for future light by simply working and watching.

Professor H. Alleyne Nicholson, F.L.S., in his two works on the 'Structure and Affinities of the Tabulate Corals of the Palæozoic Period,' 1879, p. 256; and in the 'Structure and Affinities of the Genus *Monticulipora*,' 1881, p. 62, has gone into the whole question of the apparent affinity of *Heteropora* and *Monticulipora*. As the whole of his remarks are founded upon structural evidence I willingly refer the student to the elaborate details furnished by the author. Generally I agree with Professor Nicholson, but much yet remains to be done in the correlation of the Mesozoic and Palæozoic types.

To Mr. Walford, F.G.S., of Banbury, and Mr. F. G. Longe, F.G.S., my thanks are due for help by suggestions and the loan or gift of specimens. I also thank Mr. Robert Etheridge, F.G.S., and Mr. Newton, F.G.S., for allowing me to examine specimens in the School of Mines.

The preceding list of the ranges of types may help the student of our Jurassic Polyzoa, and many of the blanks in the columns may ultimately be filled in.

References to letters in the various columns:—H., Haime; W., Walford; M., Morris' Catalogue. In the last column the figures refer to the figures at the tops of the columns.

I shall be glad to receive from any student of British or Foreign Fossil Polyzoa a list of species which are known to be present in their own neighbourhood, for the purpose of compiling a complete list of species, or as far as possible complete.

[1] 'On the Occurrence of Recent *Heteropora*,' *Jour. of Roy. Microscop. Soc.* 1879 (June).

[2] 'On Recent Species of *Heteropora*,' *Jour. of Linn. Soc.* 'Zoology,' vol. xiv. (1879).

Preliminary Report of the Committee, consisting of Professor W. C. WILLIAMSON, *and* Mr. WM. CASH (*Secretary*), *on the Flora of the 'Halifax Hard Bed,' Lower Coal Measures.*

THE present Report is on the fossil plant-remains, which are found in a singularly perfect state of preservation in a thin bed of impure coal in the 'gannister' series of Halifax and its neighbourhood, in the county of York.

Our observations relate to an examination of specimens from numerous coal-pits situated on an area extending from the vicinity of Bradford on the north to Sheffield and district on the south.

Many of the pits in the district now indicated are no longer worked, partly on account of the reduced price of coal of late years and partly because the iron pyrites brought up in working the coal (which was formerly sold for chemical purposes) has been superseded by the importation of sulphur at a cheap rate from Italy and other countries.

These influences have acted adversely upon your Committee, since some of the best pits for the special 'coal balls' in which the coal plants are found have been closed. Still, we have to report the acquisition of a goodly number of 'coal balls' which await examination. Before their contents can be properly studied they will have to be cut into thin slices preparatory to microscopical investigation. Already we have prepared upwards of one hundred microscopical slides for careful study.

Halifax appears, so far as our observations go, to be the centre of this rich Carboniferous flora. The bed in which the fossils are found is two feet three inches thick in the neighbourhood of Halifax, and consists of an impure coal, which in many places is thickly studded with nodules, or, as they are locally called, 'coal balls.' These are composed chiefly of carbonate of lime, some carbonate of magnesia, along with smaller quantities of oxide and sulphide of iron, sulphates of soda and potash, and a little silica. These nodules contain imbedded rootlets, stems, leaves, Lepidostrobi, spores, and occasionally the mycelium of fungi.

The state of preservation of the fossils is very remarkable; the tissues of the plants are infiltrated with carbonate of lime and the cell-walls are carbonised, so that in thin slices prepared for the microscope the minutest details are clearly defined.

The roof of the 'hard bed' is a thin stratum of shale filled with the flattened valves of a bivalve shell (Aviculopecten); above this is a bed of shale with numerous calcareous nodules, coated and often impregnated with iron pyrites, and containing fossil shells of the genera Aviculopecten, Goniatites, Nautilus, Orthoceras, and others, a very prevalent fossil being *Goniatites Listeri*. The base of the bed is composed of 'gannister,' and abounds in Stigmarian roots.

In the northern part of our district around Bradford the 'coal balls' are scarce, and so highly charged with iron pyrites that plant-remains suitable for microscopical examination very rarely occur. The same remark applies to Huddersfield, and in a somewhat less degree to the southern area around Hazlehead and Sheffield.

The three most prolific localities are situated at Sunny Bank, Southowram, at Sugden Pit, Bradshaw, and near Elland, all of which are in the immediate neighbourhood of Halifax, but unfortunately the two

latter pits are now closed, whilst the number of nodules brought up from the Sunny Bank Pit is much restricted. The state of preservation of the fossils is, however, most excellent, surpassing in this respect even those from the famous Oldham and other Lancashire beds.

So far as we have been able to study the fossils collected during the past year, we succeeded in throwing considerable light upon the structure of *Asterophyllites* (*Myriophylloides*) *Williamsoni*, upon *Calamostachys Binneana*, especially in relation to the structure of its central axis, upon a hitherto undescribed form of Kaloxylon, upon *Lyginodendron Oldhamium*, and several other minor forms of plants, the structure and affinities of which are as yet imperfectly understood. Indeed, an enormous amount of work remains to be done. We have already a very large number of objects with the structure of which we are well acquainted but the true botanical relations of which are entirely unknown to us. In the case of some of these, persevering research has already enabled us to ascertain those relations, and we doubt not that a continuance of that perseverance will sooner or later enable us to throw a definite light upon many of those whose botanical history is yet obscure.

The following is a list of plant-remains from the Halifax hard seam :—

Lepidodendron Selaginoides.
„ Harcourtii.
Sigillaria.
Stigmaria ficoides.
Favularia.
Dadoxylon.
Diploxylon.
Lyginodendron Oldhamium.
Lepidostrobus insignis.
Lepidostrobi (several forms).
Traquaria (auctorum).
Calamites.
Calamostachys Binneana.
Amyelon radicans.
„ radiatus.
Astromyelon.
„ (Myriophylloides) Williamsoni.
Rachiopteris Lacattii.
„ bibractiensis.
„ aspera.
„ duplex.
„ tridentata.
„ cylindrica.
Rachiopteris insignis.
„ robusta.
„ di-upsilon.
Kaloxylon Hookeri.
„ nov. sp.
Trigonocarpon olivæforme.
Lagenostoma ovoides.
„ physoides.
Cardiocarpon anomalum.
„ Butterworthi.
Zygosporites brevipes.
„ longipes.
„ oblongus.
Oidospora anomala.
Sporocarpon asteroides.
„ tubulatum.
„ ornatum.
„ elegans.
„ pachyderma.
„ compactum.
Peronosporites antiquarius.
Cistopus (?) carbonarius.
Stomata (Cordaites (?)).

We have to express our indebtedness to those indefatigable workers, Messrs. Binns and Spencer, of Halifax, for valuable assistance given in the investigation of the Halifax fossil flora.

Report of the Committee, consisting of Dr. PYE-SMITH, Dr. M. FOSTER, *and* Dr. BURDON SANDERSON, *appointed for the purpose of investigating the Influence of Bodily Exercise on the Elimination of Nitrogen (the experiments conducted by* Mr. NORTH).

IN presenting an account of the expenditure of the grant of 50*l.* made to us last year for the purpose of investigating the effect of muscular labour on the elimination of nitrogen, we beg to submit the following statement of the present position of the inquiry.

The subject naturally divides itself into two parts—(1) The analysis of the ingesta and excreta, and (2) the work. The experiments under the former head have been carried out with funds derived from another source, and have arrived at a point at which it becomes desirable to employ some means by which the relative amount of work done at different times can be compared with the utmost practicable exactitude.

The grant has been expended in providing a machine for this purpose, and for certain accessories.

The machine consists essentially of an arrangement by which a weight—the amount of which can be regulated—may be raised through a known distance and then allowed to fall to its position of rest.

Without entering into a detailed account of the apparatus it will suffice here to describe the arrangement by which the muscular recoil at the end of the stroke is got rid of.

As will be seen in the accompanying photographs,[1] the force is exerted, not directly upon the weight, but upon a cam keyed on to the same axis as the pulley which carries the weight. By means of this cam the work at the end of the stroke rapidly diminishes to practically nothing, and in consequence there is no muscular recoil. The handle by which the weight is raised carries an automatic clutch so arranged that, when the weight has been raised to a certain point, it is released. The descent of the handle by its own weight causes the clutch to part an eye on the end of the rope attached to the cam, and the operation can then be repeated. The apparatus has been so constructed that the work can be done in any position, from the vertical to the horizontal. The photographs show it arranged for the latter.

The machine is completed and ready for use, and Mr. North hopes during the ensuing year to be able to make a number of experiments with it upon the effect of varying amounts of work upon the elimination of nitrogen.

[1] These have not been engraved, as they represent the machine in a state not quite perfected.

First Report of the Committee, consisting of Professor FLOWER, Dr. BEDDOE, Mr. BRABROOK, Mr. F. GALTON, Mr. J. PARK HARRISON (*Secretary*), Dr. MUIRHEAD, General PITT-RIVERS, Mr. F. W. RUDLER, *and* Mr. CHARLES ROBERTS, *appointed for the purpose of obtaining Photographs of the Typical Races in the British Isles.*

OWING to the accumulation of observations of height, weight, and other physical characteristics of the inhabitants of the British Isles, the discussion of which required the undivided attention of the Anthropometric Committee, the acquisition of photographs undertaken by them in 1876 was last year transferred to a Committee of the Anthropological Department.

The photographic portraits already collected have been handed over to the new Committee, and will assist materially in determining the values of crosses in different parts of the country. Some, obtained under exceptionally favourable circumstances, and especially seventeen portraits of Shetland islanders, well illustrating the Scandinavian element in the population, and presented by Dr. Muirhead, may be safely termed typical.

The scientific bearing of the subject.—A clear definition of racial features, illustrated by examples, will, the Committee believe, prove of considerable importance in connection with more than one social question.

1. First; as tending to allay national animosities springing from a belief in the preponderance of some one race; and, in connection with this, affording a safe basis for generalisation, in the place of deductions depending on doubtful traditions and insufficient historical data.

2. A correct description of the main racial types would also afford an opportunity of testing in a more complete manner than is now practicable, the truth of views, believed to be extensively held, on the subject of racial tendencies and proclivities.

3. Indirectly; by indicating the way in which features, and more especially profiles, of human beings should be observed, it would lead to a more exact description of criminals and deserters; resulting, it cannot be doubted, in more frequent arrests. At present, so little attention is paid to the subject that photographs of prisoners are taken solely in full face; and the description of recruits for the military rolls is confined, so far as their features are concerned, to the colour of the hair and eyes.

The popular view regarding the possibility of a survival of racial features at the present day.—Before proceeding further, the Committee think it will be well to notice an objection, not infrequently made, that European populations are now too much mixed to allow of racial types being recognised. This is not the belief of anthropologists generally. Professor Rolleston—whose loss this Committee has especial reason to deplore—expressed no uncertain opinion on the subject in his address to the Anthropological Department at Bristol. 'At once, upon the first inspection of a series of crania, or, indeed, of heads, from such a (mixed) race,' he said it was evident that 'some were referable to one, some to another, of one, two, or three typical forms:' also that intercrossing has left the originally distinct forms still in something like their original independence, 'and in the possession of an overwhelming numerical representa-

tion:' and Professor His was quoted as having arrived at a similar conclusion from an investigation of the ethnology of Switzerland.[1]

Professor Kollmann, too, of Bale, believes that it is quite possible to distinguish original or main racial characteristics in a mixed population, owing to a capacity in skulls and facial skeletons to preserve their pristine types long after the colour of the hair and eyes have changed by crossing. A complete fusion of component elements, the distinguished Professor is convinced, never absolutely occurs.

Reversion to original types.—Besides, however, these composite forms, eminent anthropologists recognise a law through the operation of which reversion takes place, under favourable circumstances, to original types. Drs. Beddoe, Barnard Davis, Flower, Rolleston, Thurnam, and Turner, in this country, and Morton, Broca, Quatrefages, Retzius, and Virchow, abroad, are in accord in believing, from craniological evidence, that the characteristics of prehistoric races exist at the present day; Professor Quatrefages, than whom the Committee believe there could not be a safer authority, even affirming that representatives of the fossil types of man are still to be found amongst us.[2]

Height, and colour of the hair and eyes, insufficient as evidence of race.—Assuming the correctness of Professor Kollmann's deductions that hair and eyes (permanent in a pure race) change by crossing more easily than skull-forms; dark tints, except under conditions of intensity, joined with diminutive stature and complete dolichocephalism, such as unmistakably point to the race styled Iberian, simply indicate, according to the index of nigrescence established by Dr. Beddoe, more or less mixture in blood. Where, too, the hair and eyes are light, and the stature tall, in the absence of information respecting the features generally, it would be impossible to pronounce any individual to be Celt or Saxon, Dane or Swede.

Birth of parents and grandparents in the same locality no proof of race. An experiment made for the purpose of ascertaining how far the birth of parents and the grandparents, on both sides, in certain districts would assist in the selection of pure local types, resulted in the conclusion that the requirement mentioned, though securing the absence of recent foreign admixture, failed as a sufficient test, by affording no evidence that movements had not occurred in the population at an earlier date.

Photographic portraits obtained under the above-mentioned conditions do not, as a fact, assist materially in the definition of racial characteristics; the features exhibit more than one type even in districts supposed to have been peopled by a given race; though, owing to the law already alluded to, pure types may be sought for, and would more frequently be found amongst such populations than elsewhere.

This, and other considerations, led a sub-Committee, in 1880, to collect in preference, from different localities, a certain number of portraits, all of which exhibited similar features; and then an equal number distinguished by characteristics in all respects different from the first series, but equally homogeneous. They presented contrasts which appeared to be racial.

Method of Identification of Types adopted by the Committee.—Approaching the subject from the standpoint of comparative physiognomy alluded to in the last paragraph, but experimenting in the first instance on the facial

[1] *Brit. Ass. Rep.*, 1875, p. 148.

[2] *Crania Ethnica*, p. 28.

skeletons of skulls obtained from ancient tumuli and cemeteries in different parts of the British Isles, it was found on superimposing tracings of the skeleton profiles of the three main types figured in the 'Crania Britannica,' that the brows of the Brachycephalic, round-barrow type were more prominent, and the nasal bones more angular and sharply projecting, than those of the Dolichocephalic, long-barrow type; whilst brows and nasals in the Teutonic skulls (and especially those of the Saxons proper) were respectively smooth and little prominent. The main characteristics in the profiles of the Round-barrow man and the Teuton would clearly have been the high bridge of the nose of the former, and the absence of an arched nose in the Saxon.

Similar results were obtained from measurements of skulls in the Anatomical Museum at Cambridge, purchased from Dr. Thurnam by Professor Humphry, and presented by him to that University. Also some skulls in the Museum of the Royal College of Surgeons, and the Greenwell collection at Oxford, have been measured and found to exhibit the same contrasts. Mr. Harrison, who obtained the measurements for the information of the Committee, found that the mean difference in projection of the nasal bones in skulls from the round-barrows, as measured from the basion to fixed points on the dorsum and the nasion, or root of the nasal bones, is about twice that observed in purely Teutonic crania. In the fine collection of true Saxon skulls from Wiltshire, obtained by General Pitt-Rivers, the principal characteristics are a rounded forehead and smooth brow, and but little projection in the nasals; and this in the male as well as the female skulls.

The points of contrast in the skeleton features of the two races were noticed by Dr. B. Davis; but owing to Saxons and Angles being at the time he wrote considered equally Teutonic, the differences observed in some of the examples selected by him to illustrate types, are not so strongly marked as in others. Dr. Beddoe and Mr. David Mackintosh, it should be mentioned, both consider the Anglian features to have been more prominent than the Saxon.—When proceeding to define tribal differences and crosses, the nasal forms will, with other features, be subjected by the Committee to more minute examination.[1]

The above facts having been sufficiently ascertained, it was easy to compare the skeleton features of the Round-barrow man and the Saxon with profiles of living subjects in this and neighbouring countries presumably inhabited by similar populations. Whenever the osseous and other features were found to correspond, at the same time that they differed entirely from other equally well-marked types, it was assumed that the characteristics belonged to distinct races.

In the following definitions the three main types in this country are designated by capital letters, intended to be used as symbols when discussing racial crosses.

First, the Dolichocephalic Dark Type, A.—The definition of the short, narrow-headed race shown by Dr. Thurnam and Professor Boyd Dawkins to have preceded the so-called Celts, and termed by them Iberian (= the Silurian of Professor Rolleston), is at present incomplete. The forehead,

[1] Professor Flower, speaking of the racial value of the nasal bone, when describing the cranial characters of the natives of the Fiji Islands, says:—'The nose is one of the most important of the features as a characteristic of race, and its form is very accurately indicated by its bony framework' (*Jour. Anthrop. Inst.* vol. x. p. 160) Dr. Broca defines six forms.

however, appears to have been fairly vertical; the brows prominent; the nasal bones long and straight; the lower jaw weak (Rolleston); and the hair and eyes dark. Statistics of the colour of the hair and eyes, collected by Dr. Beddoe, show that this race exerted a much wider influence on the population than is usually supposed. A number of photographs, which, it is believed, represent varieties of the type, have been placed on cards.

Second, the Brachicephalic Fair Type, B.—The principal characteristics of this race consist in the prominence of the brow and supra-nasal ridges; a slightly receding forehead; sharply projecting nasal bones, causing a high-bridged or arched nose, without undulation; a long, oval face; high cheek-bones; and a prominent fine chin. From Mr. Park Harrison's observations the lips of this type appear to be thin, and the ear pear-shaped, with no proper lobe, the fossa being continuous.

The above features are found associated with light hair and eyes, and a stature above the average.

This type includes Belgic, Cymric, and Danish varieties, which further observation, the Committee believe, will in course of time enable them to differentiate: as also the Anglian, Jutish, and Frisian types. They have selected several portraits, which present common characteristics.

The definition of Type B agrees in all the main points with descriptions given some years ago by Dr. Beddoe, Mr. David Mackintosh, and Mr. Hector Maclean, as well as with Dr. Rolleston's deductions in the appendix to 'British Barrows.'

Third, the Sub-Dolichocephalic Fair Type, C.—The Committee believe that the following is a correct definition of true Saxon features. Brows smooth; forehead rounded and vertical; nasal bones short and straight; nose not arched, ending in more or less of a bulb; face elliptical, rounded; cheek-bones broad; chin rounded; lower part of face wide; eyes prominent, in colour blue or bluish-grey; lips moulded; ears flat, with formed lobes; face and frame well-covered. Height about the average.

The definition accords with Schadow's pure German (Teutonic) type, and with the Saxon type of Beddoe and Mackintosh.

Photographs conforming in all respects to the above characteristics have been obtained from Sussex and several other English counties; and from Scotland, Sweden,[1] Germany, and France. Specimens have been arranged upon cards.

No photographs have as yet been taken specially to illustrate the three types, the Committee thinking it best to proceed before doing so with the definitions of racial varieties.

New Designation of the Committee.—If reappointed, they suggest that it should be 'for the purpose of defining the facial characteristics of the races and principal crosses in the British Isles, and obtaining illustrative photographs with a view to their publication.'

Constitution of the Committee.—Professor Flower having been unable to take an active part in the proceedings of the Committee owing to pressure of other work, and having expressed a wish that another chairman should be appointed, they hope that General Pitt-Rivers will undertake the duties.

Photographs.—Mr. Barraud, who was asked to act as an associate, has presented some cabinet photographs of well-known persons for exhibition. The Committee have also received from Dr. Beddoe a portrait

[1] The Dolichocephalic Swedish race of Retzius was believed by him to be closely allied to the Saxon.

in full face and profile, taken at his expense, of a native of Montgomeryshire. Other photographs have been received in illustration of Types B and C.

The Committee ask for a renewal of the grant of 10*l.*, with an addition sufficient to procure the requisite negatives, and also photographs from different counties to illustrate crossing.

Preliminary Report of the Committee, consisting of Mr. R. MELDOLA, General PITT-RIVERS, *and* Mr. W. COLE, *appointed to investigate the Ancient Earthwork in Epping Forest, known as the Loughton Camp.*

THE earthwork known as the Loughton Camp (first identified by Mr. B. H. Cowper in 1872) is situated on an elevated plateau in Epping Forest, about a mile N.W. of the village of Loughton. There is another well-preserved earthwork in the Forest, known as Ambresbury Banks, lying about $2\frac{1}{2}$ miles due north of the present camp, and investigations undertaken last year by the Essex Field Club showed that the Ambresbury Banks entrenchment was of British or Romano-British construction (see 'Brit. Ass. Report,' 1881, p. 697). In order to carry out the systematic investigations of these two camps, which had not been cut into before the examination made last year, it was resolved to commence upon the Loughton Camp as early as possible this year, and an appeal was made to the Essex Field Club, of which the present Committee are all members, in order to raise the necessary funds. Permission having been granted by the Epping Forest Committee of the Corporation of London, the work was commenced on May 29, and was continued until June 13. The mode of working was similar to that employed at Ambresbury Banks,[1] and consisted in cutting sections through the rampart and ditch in order to expose the old surface line. With a view to facilitate the carrying on of the necessarily tedious work of watching the removal of the earth, a sub-Committee of the Essex Field Club was appointed to co-operate with the present Committee, and one or more members of the joint-Committee were present on every working day to watch the proceedings. Each spadeful of earth was sifted on its removal, and carefully examined for relics, the position of each object being entered as it was found on a working section prepared by Mr. W. D'Oyley, the honorary Surveyor to the Club. The first section was 12 feet in width, and its cutting involved the removal of 150 cubic yards of earth. But few objects were found in this cutting. On the old surface, nearly under the centre of the rampart, two or three fragments of pottery, several flint 'flakes,' and pieces of charcoal were turned up. The pottery is extremely rude, and consists of badly burnt rough clay, containing quartz grains, and showing no traces of lathe turning. The great amount of denudation which this earthwork has experienced, owing to its exposed situation and the light character of the soil, has caused the complete silting up of the ditch in most parts, and it was found in this first section that the silting was so very similar in ap-

[1] *Transactions Essex Field Club*, ii. p. 55.

pearance to the undisturbed earth, that the form of the ditch could not be satisfactorily made out. This last circumstance, combined with the paucity of the evidence obtained, determined the extension of the investigation, and another cutting 7 feet wide was commenced on June 8. In this second section no pottery was found, but numbers of flint flakes, and a partially-finished flint celt, all on the old surface line, and buried well beneath the rampart. Further evidence of human occupation in the way of charcoal and burnt clay, marking the sites of fire-places, were also found on the original surface.

The evidence thus far obtained does not appear to the Committee sufficiently complete to enable it to form any conclusive opinion as to the age of the earthworks, although the relics thus far found, conjoined with the absence of all Roman remains, point to a very early, and most probably pre-Roman, period. It is therefore proposed to continue the investigations, and we have to request that the present Committee be reappointed, with the addition of the name of Mr. Worthington G. Smith. Full details of the various objects found, with a description of the physical features of the camp and its environment, together with a complete survey, will be presented with the final Report.

In conclusion, the Committee has to express its thanks to those members of the Essex Field Club who have subscribed to the fund which has enabled the investigation to be carried out, and especially to Mr. W. D'Oyley of Loughton, who prepared the plans and sections for the use of the explorers.

Second Report of the Committee, consisting of Mr. Sclater, Mr. Howard Saunders, *and* Mr. Thiselton-Dyer (*Secretary*), *appointed for the purpose of investigating the Natural History of Timor-laut.*

By an oversight your Committee omitted to draw the sum of 50*l.* granted to them at the Swansea meeting of the Association. This grant therefore lapsed, and your Committee have had nothing more at their disposal than the 100*l.* voted by the General Committee at York.

A communication was received from Mr. Forbes's representative in London subsequent to the last meeting of the Association, in which the following statement occurs:—

'Mr. Forbes has been informed that the sending of collections to the Association is a condition annexed to all such grants as that voted for the Timor-laut expedition; and as he could not fulfil such a condition he feels compelled to postpone his expedition.'

This communication was considered by your Committee at a meeting held November 17. It was felt that the contribution made by the Association would go but a small way to cover Mr. Forbes's expenses, and that therefore any claim to the whole of the scientific results was not in any way reasonable. A communication was therefore made to Mr. Forbes to the effect that the Committee would pay the 100*l.* in their hands to Mr. Forbes 'upon condition of his undertaking to proceed to Timor-laut and make collections. Of these collections, both zoological and botanical, the first complete set is to be placed at the disposal of the

Committee. Of all other specimens Mr. Forbes is to retain uncontrolled power of disposition.'

This arrangement was accepted by Mr. Forbes by telegram on February 21 of the present year; and, as had been arranged with his representative, the time being pressing, a credit for 100*l.* was telegraphed out to him at a cost of 2*l.* 14*s.* 8*d.*

Subsequently the following letter, dated April 1882, was received from Mr. Forbes:—

'Batavia.

'My dear Sir,—I have deferred writing to you till all my arrangements for the Timor-laut expedition had been completed, and I trust you will pardon my seeming want of courtesy in not writing directly to yourself before this.

'On arrival here at the beginning of the year from Sumatra, I at once made application to the Government for the continuance of the grant of the war vessel made to me by the late Governor-General, without which it would have been almost impossible for me to have accepted the Association's grant. Last year I was under the impression that vessels belonging to certain Arabs went there every year. This I now find to be erroneous. They do not go to Timor-laut itself, nor to any of the near islands, nor is there any means of communication save from Amboina in the boats used by the tortoise-shell gatherers, which could not well take me and my baggage, nor bring back my botanical collections. I had to wait a very long time for the reply of the Governor-General—in fact, until March 12 or 13, when I telegraphed to London. My arrangements are now to leave here by the first steamer—in fact, the first since my reply from the Government here—for Amboina, where the *Tagal* is now lying. I asked that the vessel should remain with me, but the Admiral here cannot grant that, the full disposition of the steamer being in the power of the Resident (Mr. Riedel), who, I have some hope, will accompany me to the island. From the Gardens here I am taking Wardian cases; and while the vessel stays, if it be for a short time only, I shall fill them, and have them sent to Buitenzorg to be established before sending them home to Kew. Part of the duplicates must remain here, both for the purpose of replacing such as die on the way to London, and partly as the return to the Government for the use of the *Tagal*. If the natives are too hostile, I may not be able to remain entirely unprotected, but I believe they are very much more friendly than is supposed, in which Dr. Machlucho Macleay, whom I had the pleasure of meeting here recently on his way to Europe, confirms me. If so, and if the *Tagal* cannot remain with me, I shall risk residence on the island by myself and my company, and take what chance may present itself of getting off.

'The mere transport is excessively expensive—from Batavia to Amboina alone it is 40*l.* Had it been necessary for me to find my own way down to Timor-laut, 100*l.* would not have paid the expenses even of landing me there.

'I have to thank you for telegraphing to the Bank here the credit of 100*l.*, of which I was at once informed. When I have seen Mr. Riedel at Amboina, I shall write you fully of the prospects of success.

'Believe me, yours very sincerely,

(Signed) 'HENRY O. FORBES.'

From the following further communication from Mr. Forbes, which is just to hand, it will be seen that he has reached Amboina; where he is, however, delayed by unforeseen difficulties:—

'Amboina: May 8, 1882.

'Dear Mr. Dyer,—I must write you, though it can be only a line, as the steamer from which we have just disembarked carries back the mail for Europe, *viâ* Java.

'I have just seen the Resident (Mr. Riedel), who has returned only four days ago from Larat and Cera, where he has been placing *Posthonders* (nominal officials only, I imagine), and to my great regret he finds he cannot again return, the season being too far advanced for the weak state of the engines on board the *Tagal*. There is, however, here a very swift schooner, which I hope to be able to engage on moderate terms to take me down.

'The reports of the islands are so good that I am exceedingly eager to be away. The natives are not at all hostile, but require only careful and, above all, trustful treatment. From what Mr. Riedel has told me, their customs are very interesting indeed. The interior of the country does not seem to be inhabited, and there are villages only along the coast. The Resident has not been yet on the mainland of either of the great islands of Timor-laut, but the chiefs of the southern part have asked him to visit them. I wish, therefore, to get to Cera, and from that cross over to Selarve, the southern island. I shall, without fail, make my way somehow to these islands by the very first ('Makassar prahu') opportunity, if the schooner here demands a too great price. I am very hopeful that a bargain will be come to, however.

"I am hopeful that the British Association will see their way to continue to your Committee the grant of last year—perhaps somewhat increased.

'With regard,

'Believe me, yours very sincerely,

(Signed) 'HENRY O. FORBES.'

Your Committee have every reason to hope that Mr. Forbes, being now fairly launched on his enterprise, will succeed eventually in reaching Timor-laut. They therefore ask for their reappointment, and that a further sum of 100*l.* may be placed at their disposal in aid of Mr. Forbes's exploration. This sum would include a re-grant of the vote of 50*l.* made at Swansea, which has lapsed.

Looking at the extreme interest which may be anticipated from the results of Mr. Forbes's explorations in Timor-laut if carried to a successful issue, your Committee cannot doubt that the aid they ask from the Association will be more than amply justified.

Report of the Committee, consisting of Mr. F. GALTON, Dr. BEDDOE, Mr. BRABROOK (*Secretary*), Major-General PITT-RIVERS, Mr. J. PARK HARRISON, Mr. J. HEYWOOD, Mr. FRANK P. FELLOWS, Professor LEONE LEVI, Dr. F. H. MAHOMED, Sir RAWSON RAWSON, *and* Mr. C. ROBERTS, *appointed for the purpose of carrying out the recommendations of the Anthropometric Committee of* 1880, *especially as regards the anthropometry of children and of females, and the more complete discussion of the collected facts.*

I. *Anthropometry of Children.*

The Committee has obtained the following returns of the age, height, weight, and colours of eyes and hair of children of both sexes, in addition to those collected by the Anthropometric Committee in previous years :—

Source	Name of Observer	Number of Observations		
		Males	Females	Total
Queen Charlotte's Hospital	Dr. Baddeley and Dr. Leslie.	485	522	1,007
Royal Maternity Charity, Edinburgh.	Dr. Kirkpatrick . .	22	20	42
Christ's Hospital, Hertford	Mr. J. F. B. Sharpe .	—	186	186
Soldiers' Daughters' Home, Hampstead.	Return received through Gen. Boileau.	—	39	39
Merchant Seamen's Orphanage, Snaresbrook.	Mr. Hackwood . .	42	19	61
Royston, Hertford . .	Mr. Austin (through Dr. W. Ogle).	20	30	50
Magherafelt Manor, Ireland.	Through Mr. Cartwright	13	10	23
Marlborough . . .	Serjt. Purdey (through Rev. T. A. Preston).	164	205	369
Red Maids' School, Bristol	Dr. Beddoe, F.R.S. .	—	60	60
Board School, Westbourne Park.	Mrs. Mant . . .	63	77	140
Board School, Hampstead	Mr. Adams . . .	284	116	400
" " "	Mrs. Walker . . .	190	132	322
" " Kensal Town.	Mrs. Wallman . .	80	60	140
" " Lisson Grove.	Mrs. Lintern . .	198	194	392
" " "	Miss Church . .	—	290	290
Various Schools . .	Through Rev. W. Stainer	20	25	45
Infant Nursery . .	Miss Arber . . .	8	6	14
Allhallows' Mission Infant Nursery.	Sister Isabel Mary . .	9	17	26
Amesbury Workhouse .	Mr. Wilson . . .	—	30	30
Various sources . .	Mr. C. Roberts, F.R.C.S.	2,713	1,070	3,785
		4,311	3,110	7,421

II. *Anthropometry of Females.*

The Committee has obtained the following returns of the age, height, weight, and colours of hair and eyes of females above ten years of age, in addition to about 2,400 observations already in possession of the Committee:—

Source	Name of Observer	Number of Observations
Girton College, Cambridge . .	Miss Bernard	33
Newnham Hall, Cambridge . .	Miss Clough	66
Milton Mount College . . .	Miss Cooper	18
North London College . . .	Mrs. Bovell Sturge, M.D. .	26
Ladies' School, Endsleigh Gardens .	Miss Smith (through Prof. Levi)	22
,, St. Andrews, Scotland	Mrs. Wood . . . . ,	20
Clergy Daughters' School, Warrington.	Miss Graves	55
High School, Norwich . . .	Miss Wills	126
Duncan House School, Bristol .	Dr. Beddoe, F.R.S. . .	39
Whiteland's Training College . .	Rev. J. P. Faunthorpe . .	129
Stockwell Training College . .	Miss Steele	122
Soldiers' Daughters' Home . .	General Boileau . . .	140
Teachers at Board School, Hampstead	Mr. Adams	9
,, ,, Lisson Grove	Mrs. Lintern	10
General Post Office	Mr. Steet, F.R.C.S. . .	172
Mr. W. Whiteley's Shop Assistants .	Mr. C. Roberts, F.R.C.S. .	101
Natives of Flamborough . . .	General Pitt-Rivers, F.R.S. .	17
,, Harpenden, Herts . .	Mr. J. H. Gilbert, F.R.S. .	199
Royal United Hospital, Bath . .	Mr. H. Terry, F.R.C.S. . .	21
Neath, Glamorgan	Mr. J. Mills	32
Royston, Herts	Mr. Austin (through Dr. W. Ogle).	50
Kensington Workhouse . . .	Mr. Pratt	18
Various sources	Mr. C. Roberts, F.R.C.S. .	1186
		2611

III. *More complete Discussion of the Collected Data referring to Adults.*

The following additional returns relating to age, height, weight, and colours of hair and eyes of adult males have also been collected during the year, for the purpose specially of supplying deficiencies in those obtained in previous years, when distributed according to counties:—

Source	Name of Observer	Number of Observations
Natives of different counties of England, Scotland, and Wales.	Dr. Beddoe, F.R.S. . .	641
,, Dorset	Gen. Pitt-Rivers, F.R.S. .	48
,, Wilts	,,	52
,, Flamborough . . .	,,	73
,, Hertford	Mr. J. H. Gilbert, F.R.S. .	540
Volunteers, Warwick . . .	Dr. Hammond . . .	100
Workhouse, Amesbury . . .	Mr. Wilson	63
Natives of Neath	Mr. J. Mills	18
		1535

From the returns of height of adult males, as thus completed (numbering about 30,000), a map has been constructed by Mr. C. Roberts to show the average stature of the adult male population (age from 23 to 50) of the British Isles; and an enlarged copy of this map, prepared at the suggestion and expense of Mr. Heywood, will be published in the next Report of the Committee. The higher statures are indicated in this map by dark shades. Dr. Beddoe and Mr. Roberts call attention to the following points of interest in this map, but they will be treated in greater detail in a future report.

Ethnology.—The greatest stature is found in Scotland and the North of England, where the population is descended from the ancient Pictish or Cimbro-British (Galloway), the Caledonii (Perthshire), the Anglo-Danes and Norse (North and East Yorkshire, Cumberland, Westmoreland, Lincoln and Norfolk), and the more purely Anglian tribes (Lothians, Berwick and Northumberland). On the other hand, the shortest stature is found in Wales, the Welsh border counties, and the South-West of England, where the Iberian race is predominant. The counties inhabited by men of more purely Saxon descent show a medium stature.

Geology.—Allowing for the ethnological differences just mentioned, the inhabitants of elevated districts possess a greater stature than those of alluvial plains. The river-valleys of the Severn, the Thames, the Dee and Mersey, the Trent, and the fen district of Cambridge and Huntingdon show a lower stature than the surrounding counties inhabited by persons of a similar racial origin.

Climate.—The stature of the inhabitants is greater in the northern and colder than in the southern and warmer districts of the islands.

Sanitary Surroundings.—The counties which fringe the sea-coast possess a higher stature than those adjoining them but lying further inland. The lower stature of the river valleys would seem to imply that such situations are not favourable to physical development. The low position of the West Riding of Yorkshire is due to the larger town population included in the returns, and that of Durham to the larger mining population. The very low position of the home counties—Hertford, Surrey, and Middlesex—is probably due to their proximity to London. The more vigorous men are attracted by higher wages, and the more feeble overflow into those districts.

Ireland is very imperfectly represented by the Committee's returns.

The Committee has prepared a series of tables from the returns in its possession, but as these are not yet complete, and there are still some important matters to be considered, the Committee requests that it may be reappointed, with the view of completing this part of the Report next year, and digesting and presenting the fresh materials in connection with those already laid before the Association.

It is a duty which the Committee has pleasure in fulfilling to return its best thanks to the observers, named in the foregoing lists, for the valuable information which they have furnished; and also to express the satisfaction of its members with the industry and intelligence of the Assistant-Secretary, Mr. J. Henry Young, and to thank him for his attention and useful services.

Report of the Committee, consisting of Lieut.-Col. GODWIN-AUSTEN, Dr. G. HARTLAUB, Sir J. HOOKER, Dr. GÜNTHER, Mr. SEEBOHM, *and* Mr. SCLATER (*Secretary*), *appointed for the purpose of investigating the Natural History of Socotra and the adjacent Highlands of Arabia and Somali Land.*

THE balance in hand from 1870–1 (6*l.* 7*s.* 10*d.*), added to the 100*l.* granted at the York meeting, together with the amount received up to the present time by the sale of the duplicate specimens of birds and land shells, viz., 17*l.* 12*s.* 4*d.*, reduced by 7*s.* for postage, leaves a total balance in hand of 123*l.* 13*s.* 2*d.* for any future work in Socotra or on the adjacent mainland.

Since the last report was presented, Professor I. Bayley Balfour has been working, whenever his other duties have permitted, at the extensive botanical collection formed by him, to which has been added the plants collected by Schweinfurth, who has since visited the island, and who has placed the same most liberally at Professor Balfour's disposal. Some of the preliminary diagnoses have been published, which show that the different groups are very rich, and that there is a very considerable amount of work in the collection, which can only be brought out slowly. Professor Balfour, writing on June 17, says:—'I have a lot more diagnoses in press just now, and hope in August or September to complete my work on the Botany. This *émeute* in Egypt will, however, interfere, as Schweinfurth will be unable to continue his communications, and I am waiting for a lot of notes by him on many species. I only hope his collections will not be destroyed, and as he has some of my specimens at present I am somewhat anxious regarding their fate.' . . .

The rock-specimens collected by Professor Balfour have been worked out by Professor Bonney, whose report on the subject was read before the Royal Society at their last meeting of the session for 1881–2. He states that the great limestone plateau, which forms so large a part of the upland district of the island, is found, by the foraminifera present in the rock, to be of Miocene age. This is seen to rest in many places upon a floor of very ancient gneissic rock, bearing a general resemblance to the most ancient rocks of North-Western Britain and other countries. The Haggier mountains, forming the highest ground in the island, consist, so far as is shown by the specimens brought, of granites poor in mica and rich in felspar, bearing often a considerable resemblance to those of Sinai. These are traversed by dykes of felsite and other igneous rocks. To the south-east of this range is a tract occupied by red felsites and rhyolites, with some agglomerates or conglomerates. The structure of some of the former rocks renders it in the highest degree probable that they are ancient lava-flows. They are anterior in date to the Miocene limestones. These also are occasionally cut by basalts and perhaps by trachytic rocks. In the northern part of the island, beneath the limestone, is an argillite of uncertain age, and there is probably some representative of the 'Nubian sandstone.' It is, however, almost certain that for a long period anterior to the Middle Tertiary, Socotra formed part of a land surface, and it is quite possible that the summits of the Haggier mountains may not have been even then submerged. If so, the flora, and perhaps the fauna, is likely to have an exceptional interest.

As to a renewal of explorations, the Committee fear that Eastern affairs make the outlook very unsatisfactory, since it would appear that all through the East, in the vicinity of Aden especially, there is a very hostile spirit rampant against Europeans. It is hoped that there may soon be some definite settling of the excitement, but at present the Committee do not think that any plans for a future expedition can be made.

The results of the Socotran exploration have been so successful and so great, considering the small expenditure of money and time it has entailed, that the Committee trust they may see the same kind of work extended. They trust that the opportunity will not be lost of sending properly trained naturalists into the mountainous regions of Eastern Africa, which the despatch of an expedition by the Geographical Society now presents. The scientific knowledge that would be accumulated by such explorers in that lofty region would be of great interest in connection with the relations of the fauna and flora of Socotra, and not of secondary importance to purely geographical information.

For the reasons given above the Committee do not ask for any further grant at present.

Report of the Committee, consisting of Dr. M. FOSTER, Dr. PYE-SMITH, Professor HUXLEY, Dr. CARPENTER, Dr. GWYN JEFFREYS, *the late* Professor F. M. BALFOUR, *the late* Sir C. WYVILLE THOMSON, Professor RAY LANKESTER, Professor ALLMAN, *and* Mr. PERCY SLADEN (*Secretary*), *appointed for the purpose of aiding in the maintenance of the Scottish Zoological Station.*

THE Committee beg leave to report that, with the aid of the sum of 40*l.* voted last year, further investigations have been made by Mr. Romanes, F.R.S., and Professor Cossar Ewart on the 'Locomotor System of the Echinodermata.' The work of the station was carried on at Oban, where, in addition to the ordinary forms abundant on the west coast, *Antedon* was plentifully obtained for examination.

The investigators directed their attention—

1. To completing their observations on (*a*) the internal nervous system of *Echinus*; (*b*) the external nervous system of *Asterias*; and (*c*) the nature of the nervous system of *Antedon*.
2. To the effects of rotation on inverted echini.
3. To the effects of poisons on echini and other invertebrates.
4. To the natural movements of *Antedon*, and to the influence on these movements of partial destruction of the nervous system.

The publication of the results obtained at Oban is reserved until the further researches now in progress are completed this year.

It may be added that a fine specimen of the rare compound Ascidian, *Diagona violacea*, was dredged in the Sound of Mull.

During the present autumn Mr. Romanes and Professors Ewart and Schäfer are at work on the Ross-shire coast. The Committee again beg respectfully to request that a sum of 50*l.* be voted to assist in meeting the expenses of the station.

Report of the Committee, consisting of Mr. JOHN CORDEAUX, Mr. J. A. HARVIE-BROWN, Professor NEWTON, Mr. R. M. BARRINGTON, Mr. A. G. MORE, Mr. T. HARDY, *and* Mr. P. M. C. KERMODE, *appointed for the purpose of obtaining (with the consent of the Master and Brethren of the Trinity House, and of the Commissioners of Northern Lights) observations on the Migration of Birds at Lighthouses and Lightships, and of reporting on the same.*

THE General Report,[1] which comprises observations taken at all the chief stations on the east and west coasts of England and Scotland, the coasts of Ireland, Isle of Man, Channel Islands, Orkney and Shetland Isles, the Faroes, Iceland, and Heligoland, has been unavoidably delayed in printing. It will probably form a pamphlet of not less than 130 pages.

With respect to the east and west coasts of England and Scotland your Committee has again to report favourably of the observations made along our shore-lines, and at the various lighthouse and light-vessel stations, upon the migration of birds. In the northern parts of these coasts the prevailing winds were westerly to north-westerly, but from the entrance of the Firth of Forth southward easterly winds prevailed. The south-east wind which brought over vast numbers of birds as recorded at Isle of May and along the English coast, was also felt locally at Pentland Skerries—a much more northern station, and there also numbers of birds were observed. The wave of migration this season has been wide-spread upon the greater portions of our east coast-line, but north of the Firth of Forth has been much more limited, more compressed and normal. The general direction has been as before, from E. to W., or S.E. to N.W. The greatest numerical returns on the east coast of Scotland were from Isle of May, and the next greatest from Bell Rock. North of the latter birds are reported much scarcer; whilst south of the former there has been a broad stream covering the whole of our east English coast in comparatively equal proportions, and without great throbs or 'rushes.'

In spring the lines of migration are the same, the birds, however, travelling from N.W. and W. to E. and S.E.[2] The points at which birds during the spring migration have hitherto been observed to *leave the land*, are situated in Forfarshire, on its south-east or east coast, and between that point and the Bell Rock, in Scotland, and at Spurn Point on the English coast.

Further north as yet, we have no great mass of statistics to indicate any other points of departure of spring migrants.[3]

[1] *Report on the Migration of Birds in the Spring and Autumn of* 1881. West, Newman & Co., 54 Hatton Garden, London, E.C.

[2] The line of migration followed by the Grey Plover, Knot, and Bar-tailed Godwit in the spring is suggestive of an ancient coast-line which towards the end, or perhaps subsequent to the last glacial epoch, swept east or north-eastward from Holderness to Southern Scandinavia and the mouth of the Baltic. It is a striking fact, as mentioned by Mr. T. R. Mortimer in a paper read before the British Association at York, 1881, that chalk boulders south of Hornsea contain black flints, which are never found in the Yorkshire chalk, and which must have come from Norway; the flints north of Hornsea are more of the Yorkshire type, and were probably derived from Flamborough Head.

[3] The Aberdeenshire coast has sent in no returns, and we cannot help thinking

Regarding the spring migration the Bell Rock and the Isle of May have hitherto returned the fullest schedules, and very considerable numerical returns are already communicated for the 1882 report. Sandwich Terns pass every spring along the coast of Forfarshire, but shoot off from the land again, and do not breed upon many of the suitable places they pass over. Occasionally a pair of birds remain and breed, as is shown by the nesting of this species on Inch Mickary in the Firth of Forth in the past season, and on a previous occasion at the same place. In the spring birds return on the same lines they travelled in autumn, from N.W. and W. to E. and S.E. Migration has been earlier than in 1880, in many cases birds arriving in advance of recent years, this having been notably the case with some of the *Limicolæ*, such as have the widest range, and whose breeding haunts are circumpolar, that is, confined to lands surrounding the North Pole. Also in the case of the *Anatidæ*, which arrived fully a month before their average period. Spurn Point is a great point of departure on the English coast, and we have seen that Grey Plover, Knot, and Bar-tailed Godwits shoot off the land there, because while they are annually seen there and southward of it in large numbers and in full breeding dress, nowhere to the north of it do they appear except in isolated cases. Still, the routes of spring migrants, whilst they are usually more direct than those of autumn migrants, are perhaps more difficult to trace, and our data are far from perfect yet. This is in no small measure caused by the well-known fact amongst ornithologists that it is always more difficult to fix dates of departures than to fix those of arrivals.

It may be said the general features of migration with reference to lines of flight, time, height of travelling, favourable winds or otherwise, circumstances of greatest casualties at lanterns of lightships and lighthouses, are the same as set forth in previous reports; yet in 1881 we find several important variations from the normal phenomena consequent on the direction of the wind and general character of the season. From the commencement of August to the end of October the prevailing winds on the English coast have been northerly and easterly, and as far north as Isle of May and Bell Rock, whilst north of this latter point they have been more westerly, except at Pentland Skerries. The winter of 1881–82 has been remarkable for its high temperatures, no such uniformly mild season having occurred for many years in this country, and the same has been the case over the whole of Northern Europe north of latitude 50° north. As might be expected, such an exceptional season has not been without its effects upon our migrants. Fieldfares have crossed in very limited numbers, and have everywhere been remarkably scarce in localities along our east coast-lines, and on the west coast absent. Large numbers of birds which regularly arrive in the autumn, as the Greenfinch, Chaffinch, Tree-sparrow, Snow Bunting, and others, and which remain for a few days only and then pass on, have this year continued for many weeks, and even months, resorting in immense flocks to the stubbles, where they found abundant supplies of food. Snow Buntings have been considerably in excess of anything known for many years, the proportion of old birds being not more than one in a hundred.

Not the least remarkable was the influx of the larger Raptorial Birds

that there must be points of both arrival and departure in the north-east of this county, as many rare species have occurred there, judging from previous records by Edwards and others.

in a very broad fan all along our east coast, and extending from Forfarshire to the south of England, having previously crossed Heligoland on September 22nd, and the two following days. From this date, Ospreys, Rough-legged Buzzards, and others of the Raptors swarmed at many localities up to the end of October.

Hooded crows came with their usual regularity, almost to a day, the great flight crossing Heligoland on the afternoon of October 17th, and also on the 18th; there was a corresponding arrival along the entire length of the east coast of England on the night of the 17th, or early morning of the 18th, also on the 19th.

The season of 1881–82 will long be remembered by east coast ornithologists for the number of rare visitants which have appeared from time to time, driven to westward of their ordinary lines by the prevailing winds from N. and N.E. to S. and S.E. generally strong, and increasing to a severe gale. The fact of ten Ospreys having been seen or procured, has already been noticed; there were two occurrences of Tengmalms Owl, the Rustic Bunting at Spurn, Lapp Bunting at Tetney on the Lincolnshire coast, White-spotted Bluethroats at Isle of May, and at Cley in Norfolk, Glossy Ibis, five occurrences, Sabine's Gull, two on Norfolk coast, Kentish Plover, Lincolnshire, Blue-winged Teal, Teesmouth, and many others.

Again, the occurrence on the east coast of such species as the Fork-tailed Petrel, is explained by the local prevalence of westerly and northerly winds in Scotland, carrying them overland from the west coast, and then probably getting into the tracks of the easterly and northerly winds which prevailed more to the southward. Records of the Fork-tailed Petrel occur at Isle of May and several localities in England, as on the Norfolk coast.

On the west coast the fullest numerical returns are from stations for the most part south of the Firth of Clyde. A rush of migrants in September, noticeable especially on the Isle of May, was observable also at stations on the west coast south of the Firth of Clyde, and would thus appear to be a general movement.

The occurrence of the white-spotted form of the Blue-throated Warbler,[1] after a succession of tremendous gales, culminating in the dreadful hurricane of October 14th, seems to show clearly that the acts of voluntary migration do not take place in following winds. This Bluethroat was caught up and borne away *nolens volens*, and our Mid-Atlantic Notes in 1880 show similar abnormal results from the prevalence of easterly gales.

The form of the migratory movement is affected by the prevailing winds even more than the severity or otherwise of the weather.

The subject of heights of lanterns and their colours has not developed as yet any fresh facts, but with the conviction that they will yet do so the table of heights is retained. Actual experiment might set this part of the subject at rest (*vide* General Remarks E.C. Scotland, Report 1880, pp. 19, 20).

A light-vessel or two placed in an equally favourable position with—let us say—the Isle of May or the Bell Rock on the east coast, or at some point north of Tweed, would, I believe, soon show us whether the preponderance of records south of Tweed is entirely due to old-established lines of migration, or to the number of light-vessels on the English coast,

[1] I am still convinced of the accuracy of my identification of this bird.—J. A. H. B.

or partly to both. It would, we think, assist in proving or disproving theories of land-communication which have been advanced and disputed by previous writers. At present we cannot positively state from our present data whether an actual or only an apparent preponderance of birds pass south of the Tweed in autumn. It appears, however, a little curious to find a highway of migration by the Pentland Firth so much further north than the stations mentioned. Writing from North Ronaldshay, Orkney, Mr. Tulloch remarks upon the usual scarcity there, and says 'they keep more direct for the mainland;' and he remarks also upon the abundance of birds seen in September and November at Pentland Skerries, where he was light-keeper for four years. He remarks especially on the number of 'Mountain' Thrushes, Blackbirds, Owls, Woodcocks, Wrens, Robins, and Titmice which occur there when the wind is from the east, from which station there is a large numerical return this year. The isolated position of the lights at Pentland Skerries, Caithness, combined with the local prevalence of easterly winds, is perhaps sufficient to account for the large mass of the records. At all events, the returns from this station deserve special attention and study.

With a dry hot summer in Northern Europe, migration is always earlier than in years of rain and low temperature, birds breeding sooner in the former, and the nestlings, like all other young things, with dry weather and sunshine developing more rapidly. Nothing is more remarkable in the phenomena of migration than the punctuality with which certain species return in the autumn, one species regularly taking precedence of another, also in respect to the date of the arrival year after year. In the *Limicolæ* and *Anatidæ* the date of the autumn migration varies often considerably from year to year; but with some species—as the Wheatear, Redstart, Fieldfare, Redwing, Hooded-Crow, Goldcrest, Woodcock, and others—we may almost predict to a day the time of their first appearance.

The Period of the migration flight in the autumn of any particular genus or species is most probably referable to two causes: the first—one of temperature—affecting the time of nesting; the second is the period at which the young arrive at maturity, or rather that period when they throw off parental control or are thrown off themselves.

When able to act independently and procure food on their own account, they flock together and migrate in a body. We know that, with rare exceptions, the young of the year migrate some weeks in advance of the parent birds. Thus we can readily conceive the whole of the large raptorial birds nesting about the same time over widely extending districts in Northern Europe; when all the many young arrive at this self-dependent stage there would be a simultaneous movement ending in a universal migratory rush. This period of self-dependence is arrived at much more quickly in some birds than in others, for species like the Knot, Grey Plover, Godwit, and Sanderling, nesting in very high latitudes, leave our shores the last in the spring of any of the migrants, and their young are amongst the first to return in autumn. The order of migration, more especially in connection with the shore birds, is the occurrence very early in autumn —July or August—of a few old birds in summer plumage, either barren, or such, perhaps, as have been prevented nesting, then the young in large flocks, and, some weeks subsequently, old birds.

The observations taken at the various stations, both on light-vessels and from lighthouses, show a marked improvement on those of previous

years, and it will be found that the results of the investigation, as set forth in detail in the General Report, are of sufficient value and scientific interest to repay the Committee for the great outlay of time in arranging and tabulating the various returns, as well as the very considerable expenditure incurred over and above the grant of 15*l.* placed at their disposal by the Association.

With respect to the Irish coast, from the light-stations around which returns have been this year received for the first time, printed schedules were forwarded to 40 light-stations. Thirty stations replied by returning the schedules wholly or partially filled with daily entries, or by sending letters remarking on the absence of migratory birds, or on their general movements.

The inquiry has the full concurrence and assistance of the Commissioners of Irish Lights.

The returns have been as satisfactory as was anticipated for a first attempt. Some of the schedules were carefully filled; and although others contain very few entries, this is to be accounted for rather by the absence of migratory birds than by any unwillingness on the part of the light-keepers to assist us.

The observers being untrained, names have been given to birds in a few instances from which it is not easy to identify the species, and occasionally there is reason to fear one species has been mistaken for another.

Many of the stations complain of an unusual scarcity of birds last autumn. By some observers this is attributed to its stormy character, but it is also due no doubt to a general diminution of birds by reason of the great numbers which perished here in the two previous severe winters.

The daily weather charts received from the Meteorological Office, London, show the last quarter of 1881 to have been exceptional in the number and violence of its cyclonic disturbances—strong westerly and southerly winds prevailing.

In order to see more easily the effect of the weather on the movements of birds, as well as to compare the migration of one species with that of another on a given date, the entries from the schedules have been classified in chronological order. The dates of migration can also be more readily appreciated.

As might be expected, more birds have been observed on our eastern coast than elsewhere. The returns from the west coast are poor in species, especially those from Kerry, Clare, Mayo, and Donegal. The Tuskar Rock —seven miles to the S.E. of Wexford—seems likely to prove the best station on the Irish coast. Large numbers of birds passed, and hundreds were killed.

Rockabill—five miles from the Dublin coast—may prove a good station.

At the Copeland Islands, County Down, most species were noticed. This is due perhaps to careful observation as well as situation.

The general remarks from Black Rock lighthouse, County Mayo, one of the most westerly as well as one of the most isolated Irish stations, are interesting. It is desirable not to draw conclusions too hastily from the statements of untrained observers.

For the present we prefer to wait for a year or two before giving any general results. Gradually the light-keepers will, we anticipate, take a greater interest in this subject, and the schedules will be better and more accurately filled, and we have hopes that then some trustworthy conclusions

may be arrived at, but it would be premature now to generalise from the data supplied to us.

In conclusion we take this opportunity of expressing our best thanks to the Master and Elder Brethren of the Trinity House, the Commissioners of Northern Lights, and the Commissioners of Irish Lights, for their ready co-operation and assistance, through their officers and men, in the inquiry.

We respectfully request our reappointment.

Report of the Committee, consisting of the late Professor F. M. BALFOUR, Professor NEWTON, Professor HUXLEY, Mr. SCLATER, Professor RAY LANKESTER, Professor ALLMAN, Dr. M. FOSTER, *and* Mr. PERCY SLADEN (*Secretary*), *appointed for the purpose of arranging for the occupation of a Table at the Zoological Station at Naples.*

THE Report upon the Zoological Station at Naples which your Committee have the pleasure of presenting is of a highly satisfactory character. The activity and prosperity of the institution continue in a course of steady development, the number of naturalists who have visited the Station during the past year shows a regular increase, and the published results of the investigations undertaken by them stand in proportionate ratio. No better proof than this could be furnished of the important position held by the Station in relation to the progress of Zoological science generally. In the 'Bericht' for 1881, issued by Professor Dohrn, attention is very naturally drawn to this increase of working visitors, notwithstanding the fact that during the ten years which have now elapsed since the foundation of the Station at Naples nearly a dozen establishments with a similar object in view have sprung into existence elsewhere. In no instance, however, can these kindred institutions be said to rival, either in magnitude or in scope, the proportions of their Neapolitan forerunner; and a caution is very justly pronounced in the report above mentioned against the indiscriminate multiplication of small and ill-organised stations, as being a means of dissipating the pecuniary support which is necessary for the maintenance and development of an efficient establishment. From the fact that the gross income which can be regarded as obtainable for such purposes is always of a comparatively limited extent, any division of patronage necessarily tends to weaken the power and to lessen the circle of usefulness, which the perfectly organised and adequately supported establishment cannot fail to possess. This warning is the outcome of no narrow-minded fear, but of a logical inference; for the conclusion is unquestionable that three or four large and well-organised stations would be able to contribute more to the advancement of science than a number of smaller institutions, each of which, on account of the division of means and the consequent inadequate endowment, would by itself be capable of doing comparatively little. The erection of numerous stations on coasts which are neither extensive nor diversified becomes on this account extravagant, as well as detrimental to prosperity and success. According to the scheme of Dr. Dohrn, the dis-

tribution of Zoological Stations should be world-wide—not simply confined to Europe only; and further than this, means should systematically be devised for enabling naturalists to visit and to avail themselves of the opportunity of investigating unknown districts at distant stations. Upon such a basis it is not too much to say that Zoological Stations would become the recognised centres from whence the unsolved problems of Zoological Science might be approached with every prospect of successful solution. It has always been the aim of the Directorate of the Station at Naples to develop an organisation which would afford a saving to the working naturalist of the three important factors of time, space, and money. The amount of success which is obtainable in this endeavour is directly proportionate to the amount of assistance and co-operation received; and hence it follows as a consequence that the greater the patronage and support, the more speedily and the more perfectly will this object be attained.

The Publications of the Station.— In the management of the Zoological Station at Naples, especial energy is devoted to the publications issued under its auspices. The various works, which are already well before the public, have taken a place in the front rank of scientific literature; and each of the series is an undertaking worthy of the support of all biologists. It is unnecessary in the present place to do more than report that the following is the state of progress of the respective publications:—

1. Of the 'Fauna und Flora des Golfes von Neapel,' four monographs have already been issued. Monographs by Dr. Paul Mayer on the Caprellidæ, and by Dr. Grussi on the Sagittæ, are in the press; and succeeding monographs by Dr. Spengel on Balanoglossus, by Baron Valiante on the Cystosiræ, by Dr. Andres on the Actiniæ, and by Dr. Lang on the Planariæ, are in preparation. There are at present 260 subscribers for the 'Fauna und Flora' monographs—a number which cannot fail to be considerably augmented so soon as the character of the works already published is more widely known.

2. Of the 'Mittheilungen aus der Zoologischen Station,' vol. iii. part iv., and vol. iv. part i., are in the press. The former contains papers by Berthold on the Bathymetrical Distribution of the Algæ of Naples, and by Mayer on Fig Insects; and the latter part, papers by Whitman on Dicyemidæ, and by Salenski on the Development of Salpæ.

3. The 'Zoologischer Jahresbericht' for 1881 is in an advanced state —a considerable proportion being already printed off. Parts i., iii., iv., are edited by Professor J. V. Carus; part ii., by Dr. Paul Mayer.

The British Association Table.—Your Committee have much pleasure in reporting that the British Association Table has been almost continuously in use during the past year—three naturalists having worked there successively, viz., Mr. Patrick Geddes, Mr. A. G. Bourne, and Mr. Frank E. Beddard. The reports furnished by these gentlemen indicate that in each case important investigations were successfully undertaken. These reports will be found appended, along with the usual lists and detailed information courteously supplied by the staff of the Zoological Station.

Applications for the use of the table during the coming year have already been received by the Committee.

With these assurances before them of the utility of the Association table, and of its direct and fruitful application to the advancement of science, your Committee confidently recommend the renewal of the grant.

I. *Report on the Occupation of the Table by Mr. Patrick Geddes.*

I reached Naples on the 8th of October, 1881, and left on the 14th of November. My object was to determine the nature and functions of the 'yellow cells' of Radiolarians and Cœlenterates; and more especially to test the hypothesis of their algal nature—emitted by Cienkowski, and adopted by the brothers Hertwig, Korotneff, Brandt, and other naturalists. I believe I may say that the result was completely successful; but as full details of my observations and experiments are now published in a paper 'On the Nature and Functions of the "Yellow Cells" of Radiolarians and Cœlenterates' in the 'Proceedings' of the Royal Society of Edinburgh for 1881–82, I may refer to that publication.

I have only, therefore, to express my most sincere thanks to the Committee for the use of their table.

II. *Report on the Occupation of the Table by Mr. A. G. Bourne.*

When I obtained permission to occupy the table from January 1 until April 17, I did so chiefly with the intention of working at the minute anatomy and histology of the marine leeches—*Pontobdella* and *Branchellion*. During the past two years I have been working, as opportunity offered, at the comparative histology of the series of Hirudinean genera. Although every effort was made on the part of the Station, the material was not so abundant as I could have wished; *Pontobdellæ* were fairly numerous, especially towards the latter part of my stay; but of *Branchellion* only three or four specimens came to hand—the *B. torpedinis* of Savigny.

The results which I obtained in this work I shall publish in connection with a series of papers on the comparative histology of the Hirudinea. While some of these are only confirmations and enlargements of the views put forward by Leydig, De Quatrefages, and Vaillant, some are at variance with these views, and others entirely new.

Up to the time of writing this Report I have been unable to complete their working out, and so must refrain from detailing them here.

I further occupied myself with an investigation of the structure and function of the papillæ found on the ventral surface of the body in *Polynoina*, the 'inferior tubercle' of Huxley, which Grube thought might serve as a genital duct.

Surprisingly enough, this tubercle has been as a rule overlooked by systematic workers at the group. I have been enabled to satisfy myself completely that it is the terminal portion of a nephridial duct, and by means of transverse sections to make out the structure of the nephridium. When the body is distended with genital products, these are forced into the tubercles and distend them, but they lie between the wall of the nephridial duct and that of the tubercle, and do not pass to the exterior of this region; this they doubtless do by a splitting of the body-wall in some region. Such a method also obtains in other annelids, and is certainly the rule in the Archi-annelida. I have observed that in many species the 'overlapping' or 'non-meeting' condition of the elytræ is due to the state of such distension.

My sections also show the method of attachment of the elytræ, their structure, as also that of the basal portion of the notopodial and neuro-

podial cirri, which contain peculiar cells, no doubt sensory in function. The supra-œsophageal ganglion, or brain, fills the prostomium and appears to supply the prostomial tentacles and palps ('Fühlercirren' of Grube). In addition, I collected the various members of the group which appeared during my stay, and hope to revise Claparade's list of the same; his *P. Grubiana* is certainly synonymous with the *Lepidonotus clava* of Montagu, common on the coast of South Devon, while he entirely omits to mention *P.* (*Lepidasthemia*, Mgu.) *elegans*, Grube, $=$ *P. lampropthalma*, Marenzeller. I have found one species which I believe to be new.

I was anxious to trace the development of some directly developing Medusæ—*Pelagia*, *Carmarina*, or other; neither Haeckel, Fol, nor Metschnikoff had been able to demonstrate in *Carmarina* the exact method of formation of the sub-umbral cavity, &c., which I had hoped to do, but did not obtain a single egg; and while, in the case of *Pelagia*, I was able to confirm Kowalesky's account of the segmentation, my departure prevented me from carrying the developmental history further than the formation of the four-sided pyramidal gastrula.

Further, I dissected specimens of the large species of *Aplysia*, common at Naples, with a view of determining the anatomy of the renal organ. The so-called poison-gland of Della Chiaje, a grape-like organ lying to the right of Spengel's olfactory organ, has nothing to do with it; the glands which secrete the pigment are scattered follicles, lying in the substance of the free edge of the mantle, and opening on its under surface. The so-called triangular gland and renal organ, which are only two parts of the same organ, lie near the attachment of this flap; the external aperture of the organ is near the anterior attachment of the gill. The renal epithelium lines a much plicated continuous membrane, and the renal sac communicates, as has already been shown to be the case in other gastropods, with the pericardial cavity.

And lastly, at the request of Professor E. Ray Lankester, I have verified his observations on the development of autoplasts in the egg of *Loligo*, the existence of which has lately been denied by Ussow.

III. *Report on the Occupation of the Table by Mr. Frank E. Beddard.*

I occupied the British Association table from April 24 to June 9. Besides endeavouring to obtain a general acquaintance with the fauna of the coast, I devoted myself to a study of the histology of the Pedicellariæ of certain echinoderms, in continuation of an investigation recently published in the 'Transactions of the Royal Society of Edinburgh.' Although, unfortunately, my work was much interfered with by indisposition, which even obliged me to leave Naples for Ischia for a short time, I was able to collect a considerable amount of material; and hope to complete and publish my observations during the coming winter.

I wish to return my most sincere thanks to the Committee for their kindness in allowing me to use the table.

IV. *A List of the Naturalists who have worked at the Station from the end of June* 1881 *to the end of June* 1882.

Number on List	Naturalist's Name	State or Scientific Body whose Table was made use of	Duration of Occupancy	
			Arrival	Departure
181	Prof. C. Emery .	Italy . .	July 27, 1881	Sept. 24, 1881
182	Dr. Colasanti . .	Italy . . .	Aug. 10 „	Oct. 4 „
183	Dr. O. Hamann .	Saxony . .	Sept. 25 „	Feb. 18, 1882
184	Mr. A. Haddon .	Cambridge . .	Oct. 5 „	Nov. 1, 1881
185	Mr. P. Geddes . .	British Association	„ 8 „	„ 14 „
186	Dr. J. Vogel . .	Baden . . .	„ 22 „	„ 30 „
187	Mr. de Watteville .	Switzerland .	„ 29 „	June 5, 1882
188	Dr. G. Beyse . .	Prussia . .	Nov. 2 „	
189	Mr. C. O. Whitman .	—	„ 12 „	May 2 „
190	Prof. A. Weisman .	Baden . . .	„ 15 „	April 24 „
191	Stud. Witte . .	Strasburg . .	„ 15 „	Feb. 14 „
192	Dr. Korotneff . .	Russia . .	„ 29 „	Mar. 23 „
193	Dr. J. Fraipont .	Belgium . .	Dec. 30 „	April 1 „
194	Capt. G. Chierchia .	Italy . . .	„ 27 „	„ 1 „
195	Dr. A. Andres .	Italy . . .	Jan. 1, 1882	June 1 „
196	Mr. A. G. Bourne .	British Association	„ 3 „	April 14 „
197	Dr. W. Uljanin .	Russia . .	„ 7 „	„ 9 „
198	Prof. G. Fritsch .	Berlin Academy .	„ 13 „	Feb. 17 „
199	Prof. D. Brauns .	Berlin Academy .	Feb. 4 „	Mar. 18 „
200	Dr. L. Oerley . .	Hungary . .	„ 8 „	
201	Mr. W. Weldon .	Cambridge . .	„ 10 „	
202	Dr. A. Fiengha .	Italy . . .	„ 23 „	
203	Dr. T. Weyl . .	Bavaria . .	March 4 „	April 5 „
204	Dr. P. Fraisse . .	Saxony . .	„ 21 „	May 2 „
205	Dr. E. Imhof . .	Switzerland .	April 14 „	
206	Dr. v. Heydenreich .	Russia . . .	„ 17 „	„ 25 „
207	Dr. v. Mereschkowsky	Russia . .	„ 18 „	
208	Mr. F. E. Beddard .	British Association	„ 24 „	June 9 „
209	Dr. Brandt . .	Berlin Academy .	„ 25 „	

V. *A List of Papers which have been published in the year* 1881 *by the Naturalists who have occupied Tables at the Zoological Station.*

Dr. Ewald . .	Ueber den Modus der Nervenverbreitung im elektrischen Organ von Torpedo. 'Unters. Physiol. Instit. Heidelberg,' Bd. 4. 1881.
Dr. K. Brandt . .	Untersuchungen an Radiolarien. 'Monatsber. K. Akad. Wissensch. zu Berlin,' 1881.
Prof. A. Götte . .	Zur Entr.-Geschichte der Würmer. 'Zoologischer Anzeiger,' 1881.
Dr. J. Brock . .	Unters. über die Geschlechtsorgane einiger Muraenoiden. 'Mittheil. Zool. Station, Neapel,' Bd. 2, 1881.
Prof. E. Metschnikoff	Unters. über Orthonectiden 'Zeitschr. f. wiss. Zool.' Bd. 35, 1881.
„ . .	Vergleichend embryologische Studien. 'Zeitschr. f. wiss. Zool.' Bd. 36, 1881.
Dr. A. Andres . .	Prodromus neapol. actiniarum faunæ addito generalis actiniarum bibliographiæ catalogo. 'Mittheil. Zool. Station, Neapel,' Bd. 2, 1881.
„ . .	Intorno alla scissiparita delle attinie. 'Mittheil. Zool. Station, Neapel,' Bd. 3, 1881.

Dr. J. W. Spengel .	Die Geruchsorgane und das Nervensystem der Mollusken. 'Zeitschr. f. wiss. Zool.' Bd. 35, 1881.
" . .	Oligognathus Bonelliae, eine schwartzende Eunicee. 'Mittheil. Zool. Station, Neapel,' Bd. 3, 1881.
Dr. J. Gaule . .	Das Flimmerepithel der Aricia foetida. 'Archiv für Anat. u. Physiol.' 1881.
Dr. Th. Weyl .	Beobacht. über Zusammens. u. Stoffwechsel des Elektrischer Organs von Torpedo. 'Monatsber. K. Akad. Wissensch. zu Berlin,' 1881.
Prof. R. Kossmann .	Studien über Bopyriden: I. Gigantione Moebii; II. Bopyrina Virbii. 'Zeitschr. f. wissensch. Zool.' Bd. 35, 1881.
" . .	Die Entonisciden. 'Mittheil. Zool. Station, Neapel.' Bd. 3, 1881.
" . .	Studien über Bopyriden : III. Ione thoracica, &c. Ibid.
Dr. G. Vosmaer .	Vorloop. Berigt omtrent het ondezoek &c. in het Zool. Station te Napels verrigt. Haag, 1881.
Dr. W. Uljanin .	Ueber die embryonale Entwickelung des Doliolum. 'Zool. Anzeiger,' 1881.
Prof. W. Flemming.	Beiträge zur Kenntniss der Zelle und ihrer Lebenserscheinungen. 'Archiv. f. mikrosk. Anat.' Bd. 20, 1881.
Prof. E. Selenka .	Zur Entw. Gesch. der Seeplanarien. 'Biologisches Centralblatt,' Jahg. 1, 1881.
" . .	Zoologische Studien: II. Zur Entw.-Gesch. der Seeplanarien. Leipzig, 1881.
Prof. E. v. Beneden	Sur quelques points rélatifs à l'organisation et au développement des Ascidies. 'Comptes Rendus,' 1881.
" . .	Existe-t-il un Coelome chez les Ascidies? 'Zoologischer Anzeiger,' 1881.
Dr. Foettinger .	Un mot sur quelques Infusoires nouveaux parasites des Céphalopodes. 'Acad. Roy. Belg. Entr. Bull.' 3 S. T. 1, 1881.
Prof. H. Ludwig .	Zur Entw.-Gesch. des Ophiurenskelettes. 'Zeitschr. f. wissensch. Zool.' Bd. 36, 1881.
Prof. W. Salensky .	Neue Untersuch. über die embryon. Entwick. der Salpen. 'Zoologischer Anzeiger,' No. 97 u. No. 98, 1881.
Dr. E. Yung . .	Recherches expérimentales sur l'action des poisons chez les Céphalopodes. 'Mittheil. Zool. Station, Neapel,' Bd. 3, 1881.
Stud. M. Bedot .	Sur la faune des Siphonophores du Golfe de Naples. 'Mittheil. Zool. Station, Neapel,' Bd. 3, 1881.
Dr. W. Giesbrecht .	Zur Schneidetechnik. 'Zoologischer Anzeiger,' 1881.
" . .	Methode zur Anfertigung von Serien-Präparaten. 'Mittheil. Zool. Station, Neapel,' Bd. 3, 1881.
Prof. C. Hofmann .	Zur Ontogenie der Knochenfische. Amsterdam, 1881.
Dr. A. Della Valle .	Nuove Contribuzioni alla Storia Nat. delle Ascidie composte del Golfo di Napoli. 'Reale Accad dei Lincei,' 1880–81.
Dr. MacLeod . .	Recherch. sur la Struct. et le Dével. de l'Appareil Reprod. femelle des Téléostiens. 'Extr. des Archives de Biologie,' vol. ii. 1881.
Dr. C. de Mereschkowski	Sur la tétronérythrine dans le règne animal, et sur son rôle physiologique. 'Comptes Rendus,' No. 24, 1881.
" . .	Les Crustacés inférieurs distinguent-ils les couleurs? Ibid. No. 26, 1881.
Prof. A. Du Plessis .	Rémarques sur les Métamorphoses de la Cassiopée Bourbonnienne. 'Bull. Soc. Vaud,' 2 S. vol. xviii. 1881.

VI. *A List of Naturalists to whom Specimens have been sent from the end of June* 1881 *to the end of June* 1882.

				fr. c.
1881.	June 26	Dr. MacLeod, Ghent . .	Mollusca	21·50
	Aug. 1	Prof. von Koch, Darmstadt .	Annelida, Brachiopoda .	29·50
	" 14	Professor Salensky, University, Kasan	Various classes . .	458·20
	" 14	Prof. Salensky, Veterinary College, Kasan	All classes . . .	2419·

				Fr. c.
1881	Aug. 24	Prof. Giglioli, Florence	Fishes	68·
	„ 29	W. Leche, Stockholm	Various classes	39·80
	„ 29	Prof. A. M. Marshall, Manchester	Various classes	420·
	„ 29	Prof. A. Brandt, St. Petersburg	All classes	178·45
	Sept. 4	Prof. W. Berlin, Amsterdam	Various classes	149·80
	„ 4	Dr. L. Eger, Vienna	All classes	423·35
	„ 5	E. A. Birge (?) England	Larvæ of Crustacea	17·25
	„ 12	T. Martisz, Buda-Pest	Various classes	31·65
	„ 16	Prof. W. Bridge, Birmingham	Fishes and Tunicata	217·
	„ 23	C. Vetter, Hamburg	Various classes	192·60
	„ 28	Prof. Emery, Bologna	Various classes	321·75
	„ 28	Prof. J. Young, Glasgow	Various classes	gratis
	Oct. 2	Prof. Butschli, Heidelberg	Cassiopeia, Siphonoph.	8·
	„ 2	Zoologisches Institut, Heidelberg	Various classes	38·10
	„ 9	Prof. R. Kossmann, Heidelberg	Various classes	44·15
	„ 9	University, Charkoff	Various classes	33·50
	„ 9	Veterinary College, Charkoff	Various classes	125·75
	„ 12	Dr. Hubrecht, Leyden	Chiton	4·60
	„ 15	Prof. Sollas, Bristol	All classes	611·80
	Nov. 5	Prof. Villanova, Madrid	Various classes	421·15
	„ 5	Zoolog. Institut, Würzburg	Mollusca, Scalpellum	9·
	„ 10	Prof. Wilckens, Vienna	Various classes	72·30
	„ 10	Dr. Batelli, Arezzo	Cœlent., Ascidia, Mollusca	64·30
	„ 10	Prof. Ehlers, Göttingen	Various classes	165·30
	„ 18	Mr. John Murray, Edinburgh	Foraminifera	gratis
	„ 12	Prof. Bergh, Copenhagen	Doris	gratis
	„ 18	Dr. Thum, Leipzig	Various classes	38·85
	„ 18	Prof. Todaro, Rome	Various classes	48·35
	„ 30	Prof. Ludwig, Giessen	Various classes	131·80
	„ 30	Graf Béla Haller, Vienna	Dolium	18·25
	„ 30	Prof. Wagner, St. Petersburg	Various classes	809·30
	„ 30	Prof. Goette, Strasburg	Various classes	911·
	Dec. 8	Mr. G. Brook, Huddersfield	Larvæ of Crustacea	7·
	„ 10	Dr. Kraepelin, Hamburg	Elementary collection	178·10
	„ 10	Dr. Andreae, Ruhrort a. Rh.	Sipunculus	21·85
	„ 10	Prof. Giglioli, Florence	Fishes	65·25
	„ 10	Dr. Hubrecht, Leyden	Terebratula	25
	„ 12	Prof. Licopoli, Naples	Various classes	20
1882.	Jan. 10	Dr. Eger, Vienna	Comatula	4·
	„ 21	Prof. de Sanctis, Rome	All classes	673·90
	„ 21	Prof. Balfour, Cambridge	Various classes	65·70
	„ 25	M. de Loriol, Chalet des Bois	Diadema	22·50
	„ 31	Prof. T. E. Schulze, Gratz	Cœlenterata, Salpæ	36·15
	Feb. 6	Prof. du Plessis, Lausanne	Cœlenterata, Bryozoa	13·30
	„ 6	Mr. Bolles Lee, Florence	Sponges	5·40
	„ 10	Prof. Seguenza, Messina	Comatula	9·30
	„ 10	Prof. Steindachner, Vienna	Fishes	gratis
	„ 10	Prof. Marenzeller, Vienna	Annelida	18·
	„ 25	Prof. Fritsch, Berlin	Various classes	201·40
	March 6	Prof. Marenzeller, Vienna	Various classes	347·75
	„ 4	Dr. Czeschka, Gratz	Cephalopoda	21·75
	„ 1	Dr. Krukenberg, Heidelberg	Muræna	6·95
	„ 12	Grand Duke George of Russia	Various classes	429·60
	„ 12	Dr. Carrière, Munich	Heteropoda	4·75
	„ 12	Dr. L. Eger, Vienna	Caryophyllia	2·50
	„ 16	N. Fenoult and Co., St. Petersburg	Various classes	134·30
	„ 13	Prof. Herdmann, Liverpool	Various classes	32·75
	„ 13	Mr. Higgins, Liverpool	Various classes	18·20
	„ 20	Prof. Whitman, Naples	Annelida, Cephalopoda	96·85
	„ 30	Zoolog. Museum of Berne	Various classes	220·10

					Fr. c.
1882.	April 12	Prof. Margo, Buda-Pest	Various classes, for anatomy		gratis
	„ 14	Dr. B. Grassi, Heidelberg	Embryos of Elasmobranchs		50·
	„ 17	Prof. Arm. Sabatier, Monpellier	Amphioxus		7·
	„ 21	Birfelder, Stuttgart	Various classes		15·
	May 1	Prof. F. E. Schulze, Gratz	Various classes		125·25
	„ 4	Dr. L. Eger, Vienna	Various classes		112·
	„ 4	Dr. Hamann, Jena	Ambulacra of Echinus		3·75
	„ 4	Prof. Moseley, Oxford	Various classes		214·50
	„ 6	Prof. Vogt, Geneva	Various classes		282·70
	„ 10	Prof. Stepanoff, Charkoff	Various classes		76·40
	„ 10	Prof. Emery, Bologna	Testudo græca		7·
	„ 10	Dr. Brock, Göttingen	Various specimens for Histology		16·75
	„ 22	Museum of Natural History, Dublin	All classes		1595·30
	„ 23	Zoological Laboratory, Heidelberg	Various classes		73·70
	„ 24	Dr. Sochaczewer, Berlin	Gasteropoda		23·75
	„ 24	Prof. Wartmann, St. Gall	Fishes		100·
	„ 24	Dr. Schulgin, Villafranca	Embryos of Cephalopoda		60·
	June 5	Prof. Weismann, Freiburg, i. Br.	Various classes		757·85
	„ 5	Prof. H. Ludwig, Giessen	Echinodermata Sepia Amphioxus	for anatomy	182·75
	„ 13	Dr. J. Carrière, Munich	Charybdæa, Mollusca		18·60
	„ 14	Prof. A. Quennerstedt, Lund	Various classes		306·70
	„ 19	Prof. R. Hertwig, Koenigsberg	Various classes		178·05
	„ 22	Prof. L. di Majo, Naples	Various classes		gratis
					15444·15

VII. *A List of Naturalists to whom Microscopic Preparations have been sent from the end of June* 1881 *up to June* 1882.

					Fr. c.
1881.	July 25	Prof. W. Leche, Stockholm	51	preparations	117·45
	„ 25	Prof. Plateau, Ghent	47	„	115·70
	„ 25	Prof. van Bambeke, Ghent	15	„	218·
	„ 25	Prof. von Koch, Darmstadt	25	„	45·50
	„ 25	Prof. Kuhne, Heidelberg	4	„	13·30
	„ 25	Prof. Salensky, Kasan	6	„	12·
	„ 25	Prof. Salensky, Veterinary College, Kasan	33	„	73·50
	Aug. 11	Henri van Havermaet, Brussels	11	„	23·
	Sept. 29	Prof. A. M. Marshall, Manchester	29	„	66·50
	Oct. 4	Prof. R. Kossmann, Heidelberg	15	„	34·75
	„ 7	Dr. Stepanoff, Charkoff	42	„	94·
	„ 12	Prof. Vogt, Geneva	45	„	72·85
	„ 15	Prof. Sollas, Bristol	127	„	286·55
	„ 26	Prof. Pedicini, Rome	5	„	5·25
	„ 30	Prof. Haddon, Dublin	64	„	139·
	Nov. 14	Prof. Todaro, Rome	43	„	104·50
	„ 14	Mr. Patrick Geddes, Edinburgh	55	„	120·
	„ 15	Prof. M. Wagner, St. Petersburg	61	„	136·25
	„ 16	L. Dreyfus, London	259	„	189·50
	„ 17	University of Wisconsin	47	„	119·85
	„ 26	Dr. Guida, Naples	22	„	30·
	Dec. 6	Dr. R. Renzone, Naples	5	„	7·25
	„ 20	L. Ward, Manchester. On commission 745 preparations, = 1094 fr. 20 c.	sold	„	129·50
	„ 28	Prof. T. E. Schulze, Gratz	10	„	23·25
	„ 28	Prof. Moseley, Oxford	97	„	214·35
	„ 31	Science and Art Department, London	52	„	105·95
1882.	Feb. 22	Edmund Wheeler, London	225	„	250·

						Fr. c.
1882.	Feb. 10	Gustav Schneider, Basle. On commission 2010 preparations, =2,625 fr.			„	
	„ 13	Prof. Fritsch, Berlin	26		„	50·
	„ 14	E. Ward, Manchester. On commission 103 preparations, = 15,750 fr.				
	„ 18	Prof. H. J. von Ankum, Groningen	66		„	133·75
	„ 24	R. and J. Beck, London	224		„	250·
	„ 24	C. Baker, London	227		„	250·
	„ 24	L. Dreyfus, London	35		„	65·
	Mar. 12	Térisse, Castellamare	18		„	30·
	April 8	Prof. Emery, Bologna	6		„	8·
	„ 11	Gibson Carmichael, Naples	11		„	20·
	„ 14	Prof. Lankester, London	35		„	80·50
	„ 18	Prof Mojisisovitz, Gratz	55		„	103·25
	„ 18	Prof. Haddon, Dublin	19		„	33·
						3581·25

Report of the Committee, consisting of JAMES GLAISHER (*Secretary*), *the* Rev. Canon TRISTRAM, *and the* Rev. F. LAWRENCE, *appointed for the purpose of promoting the Survey of Eastern Palestine.*

WE have to report, as regards the survey of Eastern Palestine, that the Committee of the Palestine Exploration Fund were able, in the spring of last year, to organise and equip an expedition for the execution of this important work. They were able to secure the services of Captain Conder, R.E., formerly in charge of the survey of Western Palestine, and they were granted by the War Office the services of Lieutenant Mantell, R.E., a young officer who had recently left Chatham. They were also able to re-engage Messrs. Black and Armstrong, now pensioners of the Royal Engineers. The party left England on March 16, 1881, arriving at Beyrout early in April. Their instructions were, on receiving the instruments, which were not quite ready when they left England, to begin the survey in the north, and to make as much use of the friendly Druses as possible. Unfortunately, a revolt of these people made work in the Hauran impossible, and it was finally decided by Captain Conder to commence in the south, where it appeared probable that operations could be conducted with safety. Accordingly he led his party across the Jordan, and commenced and carried on the survey for some months.

Unfortunately it had been discovered by the Turkish authorities that the firman with which our party worked was one issued by a former Sultan, and that it did not convey the power of working east of the Jordan. Peremptory orders were received from Constantinople that the work was to be stopped immediately. But by this time 500 square miles of the survey had been accomplished.

Efforts were made by the Foreign Office, by Lord Dufferin, and by Captain Conder himself, to obtain a new firman. The matter is so far advanced that a firman has been promised. But it is not yet signed.

Captain Conder kept his party in winter quarters at Jerusalem, where they were employed in laying down the work and calculating the observations and making fair drawings of the plans. In the April of the year their Royal Highnesses Princes Edward and George of Wales reached Palestine, and Captain Conder was commanded to attend them on their tour, which lasted six weeks. In the course of the journey the Mosque

of Hebron was visited, and an accurate plan taken by Captain Conder. The party also spent a week on the eastern side of the Jordan.

Captain Conder retired from the country on May 22 of this year. Before leaving Palestine he received notice from His Excellency the British Ambassador that the new firman had been finally approved by the Minister of Public Instruction, and submitted by him to the Porte for confirmation. He has brought home with him the finished map, on the scale of 1 inch to the mile, of 500 square miles, together with many new photographs taken by Lieutenant Mantell, and volumes of notes, special plans, drawings, &c. He is now occupied in working up for publication the notes and information collected by him. This will occupy him about five months.

The results of this campaign have been, among other things, the discovery of a vast number of cromlechs and rude stone monuments. Many of them had been discovered previously by Canon Tristram, but Captain Conder has established the fact that this part of Moab was a great centre of the form of religious worship of which these monuments are the remains. He suggests that among them are the altars of Balak. He has proposed identifications for Baal Peor, the Field of Zophim, the Ascent of Luhith, Jazer, Sibmah, and Minnith—six Biblical places previously unknown; he has collected a great quantity of Arab folk-lore, with tribe marks and traditions; he has found a most remarkable building of Persian character at Ammân; and he has made a collection of sketches and plans of the greatest value. In fact, the work done on the east of the Jordan will be found to be in every way equal to that done in the west and already published. He has also made numerous geological observations. But besides the survey, Captain Conder found time to do a great deal of work on this side of the river. He discovered Kadesh, the ancient capital of the Hittites; he has measured and planned the Siloam tunnel, and made a copy of the inscription; and he has discovered and planned what he suggests may be nothing less than the real Holy Sepulchre.

It is hoped that the party may again before long take the field, without fear of obstruction or opposition, in a work which has no political significance, but is of extraordinary interest to all who are interested in the lands and people of the Bible.

Report of the Committee, consisting of Professor LEONE LEVI, Mr. STEPHEN BOURNE, Dr. HANCOCK, *the late* Sir ANTONIO BRADY, *the late* Professor JEVONS, Mr. F. P. FELLOWS, Mr. E. J. WATHERSTON, Mr. PEARSON HILL, Mr. GEORGE BADEN POWELL, *and* Mr. JEREMIAH HEAD, *appointed for the purpose of continuing the inquiry into and completing the report upon the Appropriation of Wages and other sources of income, and considering how far it is consonant with the economic progress of the United Kingdom. Drawn up by* Professor LEONE LEVI.

THE question, whether or not, or how far, the present appropriation of wages and other sources of income is consonant with the economic progress of the people of the United Kingdom, is one of considerable

importance, the consumption of wealth forming one of the great divisions of political economy, though it has received but scanty attention from English writers on that science. The question, indeed, does not admit of exact statistical analysis, the personal expenditure of the people being of an elastic character, and depending, in a great measure, on the varying wants of man, which seem to increase with the power of satisfying them. It is easy to say that the wages and other sources of income are appropriated in accordance with the economic progress of the people in proportion as they are expended in articles directed to maintain, or to add to, the productive forces of the nation, but there remains the grave difficulty to define what is necessary for such maintenance or addition, and upon this the opinions of men differ considerably.

Man's real wants are very few. 'Allow not nature more than nature needs; man's life is cheap as beasts'.' But increasing civilisation produces increasing wants. It is not only our physical wants that we have to satisfy, but our moral and intellectual wants. The boundary-line between the necessary and the luxurious cannot well be marked. Luxury is a relative term. It has been defined as the use of the superfluous; but what is superfluous in one state of society, or to one class in society, may be necessary in another state or to another class. Tea, sugar, wheaten bread, meat, and even the education of children, were accounted as superfluities in England years ago. They are now necessaries, even to working men. Luxury does not necessarily consist of whatever is costly. The most costly things are often the most economical. Wants differ greatly. A man of letters may find it necessary to possess a well-stored library; a man of taste, an artist, will require works of art; a person of position and rank will need a residence suited to his condition. What is necessary to one who spends a life of labour and industry may be useless to another who indulges in *dolce far niente*. For the performance of intellectual, and even manual, labour of the highest order, comforts and conveniences are needed which may appear luxuries and superfluities to those incapable of such efforts.

There is a considerable difference, however, between what is expended in pure luxuries, such as ornaments and legitimate pleasures, and what is expended in dissipation, vice, or in the absolute destruction of wealth. Ornaments and legitimate pleasure may, both directly and indirectly, promote production, as an occasional amusement may lighten the mind, and make it the better fitted for close application; but dissipation and vice are directly antagonistic to the production and maintenance of wealth. Luxury manifests itself in the prodigal use of jewellery, the expensiveness of entertainments, the richness of female apparel, the gorgeousness of Court pageantry, and the magnificence of household furniture and appointments. Luxury, it has been said, is the indigenous product of monarchies, monarchs having always found it useful to require a high etiquette and an imposing external to maintain power. But luxury of this nature is not confined to Courts. It is the child of wealth and pomp among the higher classes, greedily followed and copied by the lower. Luxury of such a character is condemned by moralists as intended to satisfy vanity and to engender egoism and ostentation. What political economy especially condemns is whatever is hurtful to the productive forces of the nation. An inordinate and wasteful indulgence in alcoholic drinks and tobacco in England, in the same manner as in opium in China and absinthe in France, is condemned by economic science because it

paralyses the productive forces of the nation. And so is war, with all its incidents; the maintenance of large armies and navies, the destruction of property, and the exhaustion of capital in every form.

In the report laid before the Association meeting at York last year many valuable facts were presented illustrative of the personal expenditure of the people of the United Kingdom derived from the quantities of produce and manufacture annually consumed and valued at import and retail prices, both exclusive and inclusive of import and excise duties, as well as of expenses and profits of distribution. Though, as your Committee have already stated, the question at issue is not capable of correct statistical analysis, and the values are, at best, estimates, the facts collected may be taken as sufficiently near the truth. For the purpose of this calculation the population was taken at 25,200,000. In estimating the income the number of paupers, sick and old, must be considered, but it should be remembered that only a small proportion of paupers are able-bodied, and that these are in the great majority not idlers, but persons earning insufficient wages, the low rates of which contribute to lower the estimated earnings for the whole number. The broad results, in their aggregate, were that the gross or personal expenditure of the people may be taken to amount to about 870,000,000*l.*, and the net, or national, to about 684,700,000*l.*

Upon these figures some emendations are required. The house-rent, deduced from the amount assessed to the Inhabited House duty, is made on the full value, and not on four-fifths, as for the poor-rate as previously calculated. We must, therefore, remove the 8,000,000*l.* added for that purpose. The amount of house-rent in Ireland may be estimated from the value of messuages charged to income-tax, which was 2,200,000*l.* Add twenty per cent. to that amount, which is too low according to Griffiths' valuation, to arrive at the present rate, viz. 800,000*l.*, and take two-thirds of the whole amount, so as to exclude shops, &c., we obtain the amount of house-rent in Ireland, 2,700,000*l.* Hence the total gross or personal expenditure in house-rent may safely be taken at 71,700,000*l.* and the net at 67,400,000*l.* The attention of the Committee has been called to the large expenditure in locomotion, apart from that included under the heading of amusements. It is difficult, however, to distinguish the personal from the business expenditure in locomotion. The gross receipts from passenger traffic on the railways amounted to 26,000,000*l.*; add 6,000,000*l.* for tramways, cabs, and omnibuses, and we have a total of 30,000,000*l.* But of this amount only one-fourth can be taken as representing the personal expenditure, or about 7,500,000*l.*, only 40 per cent. of which would represent the real expenditure in the maintenance of way, locomotive power, horses, &c., or 3,000,000*l.* Another omission has been noted, viz., the expenditure on domestic service. Such expenditure is, however, included in the cost of the articles which servants consume, the remainder constituting a simple transfer from one class to another. The same observation will apply to other branches of expenditure, as the medical, lawyers' fees, &c.

Making the necessary alterations, the total expenditure is as follows:—

	Gross or Personal		Net or National	
	£	Per cent.	£	Per cent.
Food and Drink . .	500,400,000	56·9	349,200,000	51·1
Dress	147,800,000	16·8	123,300,000	18·0
House, &c. . . .	116,400,000	13·2	103,400,000	15·3
Tobacco	13,100,000	1·5	3,000,000	·4
Education, Literature, &c.	23,000,000	2·6	10,700,000	1·6
Church	12,000,000	1·4	2,400,000	·3
Locomotion . . .	7,000,000	0·8	3,000,000	·4
Amusements . . .	12,500,000	1·4	3,100,000	·4
Taxes	47,500,000	5·4	7,000,000	1·0
Cost of distribution . .	—	—	77,500,000	11·5
	879,700,000	100	682,600,000	100·0

On examination of the component parts of these various items of expenditure it will be found that, whilst the expenditure on articles of food consists mostly of necessaries, the expenditure on drink includes a large amount for beer, spirits, and wine, only a small portion of which, probably twenty per cent., can be supposed to be necessary, the remainder being either pure luxury or sheer waste. The expenditure on dress includes silk, lace, embroideries, gold and silver and jewellery, which are luxuries. The house expenditure, inclusive of furniture, fire, and light, is necessary, though a considerable portion of furniture of the larger houses is certainly of a luxurious character. The expenditure on tobacco is altogether luxury, if not waste. Education, literature, and newspapers are necessaries in this age of intellectual progress. The expenditure on theatres and other amusements is, for the most part, luxury. Taxes, in so far as they are levied to defray the cost of maintenance of order and improvements, are necessaries. Collectively, out of a gross personal expenditure, amounting to about 879,700,000*l.*, about 728,000,000*l.* are probably spent on necessaries and 150,000,000*l.* on luxuries and waste, that is, about 83 per cent. in necessaries and 17 per cent. in luxuries. Out of a net, or national, expenditure of about 682,600,000*l.*, about 614,000,000*l.* are probably spent on necessaries and about 70,000,000*l.* on luxuries, that is, 89 per cent. on necessaries and 10 per cent. on luxuries. The nation, in reality, spends only the half of what the individuals spend on luxuries, because large portions of these consist in taxes and profits of distribution which remain in the country.

Of late years the expenditure on the necessaries of life has greatly increased. The expenditure on house-rent especially so, partly from the increased cost of houses, and partly from the greater capacity of the people to enjoy the comfort of a commodious home. The amount upon which the house-duty on dwelling-houses was charged has increased as follows:—

Year	Amount charged £	Year	Amount charged £
1856 . . .	14,297,000	1871 . . .	25,461,000
1861 . . .	16,499,000	1876 . . .	30,458,000
1866 . . .	20,826,000	1881 . . .	38,732,000

The following comparison of the number of houses at different rentals in Great Britain in 1831 and 1881 absolutely, and in proportion to population, shows a large increase in the number of persons living in houses

at higher rents—another evidence of the increasing prosperity of the country and of the productive manner in which the money is spent:—

Rentals	1831		1881		Increase per cent.
	Number of Houses	Number per 1,000,000 of Population	Number of Houses	Number per 1,000,000 of Population	
20*l.* and under 50*l.*	159,905	9,750	515,019	17,340	78
50*l.* „ „ 100*l.*	41,088	2,504	149,093	5,019	100
100*l.* „ „ 150*l.*	8,728	532	37,859	1,274	139
150*l.* „ „ 300*l.*	4,625	282	24,062	810	187
300*l.* and upwards	1,038	63	8,438	284	350
	215,384	13,131	734,471	24,727	88

The distinction made in the object of the Committee's researches between the wages and other sources of income suggests the inquiry into the relative amount of expenditure by the labouring, middle, and higher classes. It is difficult to ascertain the number belonging to each, the different classes merging into one another. The Inland Revenue Commissioners give the number of dwelling-houses in Great Britain in the year 1880–81 as follows:—

	Number
Under 10*l.*	3,111,039
10*l.* and under 15*l.*	778,935
15*l.* „ „ 20*l.*	441,729
20*l.* and upwards	734,471
	5,066,174

Assuming the houses charged to house-duty at 20*l.* and upward to represent the proportion of the middle and higher classes, and those not so charged to represent the proportion of the working classes, the proportions would be 86 per cent. of the labouring to 14 per cent. of the middle and higher classes. It should be remembered, however, that the great number of lodgers of all classes renders the house-test most imperfect. Moreover, many foremen, clerks, and teachers occupy houses at comparatively low rentals, just as many of the labouring classes occupy houses at high rentals, divided and subdivided, however, between many families. Altogether, there is reason to believe that the labouring classes represent 70 per cent. of the population and the middle and higher 30 per cent. In other words, 246,000,000 persons, 54,000,000 families, at 4·5 persons each, may be taken to belong to the labouring classes, and 10,500,000 persons or 2,300,000 families, to the middle and higher classes.

Upon this basis we may now endeavour to estimate the proportionate expenditure of the labouring and middle and higher classes respectively. We cannot assume the personal consumption of the labouring classes to be equal to that of the middle and higher classes in quantities and value, though the larger number of the labouring classes tends to equalise, in many cases, the total amount of expenditure of both. It is well known, moreover, that whilst beer is more largely consumed by the labouring classes wine is mainly used by the middle and higher classes; cotton and wool constitute the dress of the labouring classes, linen and silk are more largely used by the middle and higher. Bearing in mind these and other

facts, well ascertained, the following may be taken as an approximate division of the expenditure:—

Gross or Personal Expenditure.

	Working Classes		Middle and Higher Classes	
	£	Per cent.	£	Per cent.
Food and Drink . .	299,400,000	71·01	201,000,000	43·84
Dress	61,800,000	14·66	86,000,000	18·76
House	39,300,000	9·34	77,100,000	16·87
Tobacco	9,200,000	2·18	3,900,000	·85
Education, &c. . . .	4,200,000	1·00	30,800,000	6·72
Amusements . . .	1,900,000	·45	10,600,000	2·32
Taxes	4,700,000	1·12	42,800,000	9·34
Locomotion . . .	1,000,000	·24	6,000,000	1·30
Cost of distribution .	—	—	—	—
	421,500,000	100	458,200,000	100

Net or National Expenditure.

	Working Classes		Middle and Higher Classes	
	£	Per cent.	£	Per cent.
Food and Drink . .	203,200,000	60·96	146,000,000	41·54
Dress	51,600,000	15·48	71,700,000	20·45
House	35,500,000	11·26	67,900,000	20·19
Tobacco	2,100,000	·63	900,000	·25
Education, &c. . . .	1,800,000	·54	11,300,000	3·21
Amusements . . .	400,000	·12	2,700,000	·77
Taxes	700,000	·21	6,300,000	1·79
Locomotion . . .	400,000	—	2,600,000	—
Cost of distribution .	36,000,000	10·80	41,500,000	1·80
	331,700,000	100	350,900,000	100

If we distribute the expenditure in silk, gold and silver plate, tobacco, beer, spirits, wine and other luxuries, amounting in all to about 150,000,000*l.* gross amount, and 70,000,000*l.* net amount between the labouring and middle and higher classes, the proportion may be estimated as follows:—

	Working Classes			
	Personal Expenditure	Per cent.	National Expenditure	Per cent.
	£		£	
Necessaries	336,000,000	80	298,700,000	90
Luxuries	85,500,000	20	33,000,000	10
	421,500,000	100	331,700,000	100
	Middle and Higher Classes			
Necessaries	394,000,000	86	314,200,000	89
Luxuries	64,200,000	14	36,700,000	11
	458,200,000	100	350,900,000	100

The working classes appear thus to devote a larger proportion of their incomes to luxuries than the middle and higher classes, a fact all the more to be regretted since the working classes are thereby left with so much less available for the necessaries of life. Luxuries may be indulged in after the necessaries of life are fully provided for, and a proportional surplus for saving has been secured. They should not be indulged in at the expense of the necessaries of life, or before a proportional surplus for saving has been secured.

Thus classified we have an average gross or personal expenditure of 28*s*. per week for each working man's family, and of 73*s*. a week for each of the middle and higher classes' family, and an average net or national expenditure of 23*s*. for each workman's family, and 55*s*. for each middle and higher class family.

In the previous report the income of the people of the United Kingdom was estimated as follows:—

	Assesssed for Income-tax £	Charged £
Income of the middle and higher classes	578,046,297	490,425,774
Income of non-income-tax payers, lower middle and working classes	*500,000,000*	*500,000,000*

Assuming the average income of the working classes at 30*s*. per week per family, including two earners each, their total earnings would amount to 430,000,000*l*., leaving 70,000,000*l*. as the income of the lower middle class. The classification made of the expenditure renders it necessary to take the income of the working classes separately, and, by placing the income against the expenditure, we have the following results:—

	Working Classes £	Middle and Higher Classes £
Income	430,000,000	578,000,000
Expenditure	421,000,000	458,000,000
Excess	9,000,000	120,000,000

Your Committee are conscious of the extreme difficulty of tracing *all* the expenditure of the different classes of society. It should be remarked, also, that some portion of the expenditure of the working classes, such as the cost of food, clothing, &c., of domestic servants, paupers, prisoners, is really disbursed by the middle and higher classes or defrayed by public or local taxes. Allowing for a great margin of error, which in the nature of the inquiry it is all but impossible to avert, the general results of the inquiry are not discouraging. It is gratifying to know that the great bulk of the income of the people is productively expended, and that though much is devoted to luxury, and a goodly portion is wasted, still a handsome annual surplus remains for reproduction, which goes to swell the capital of the nation.

The subject under consideration is of the highest practical importance, and its lessons cannot be too extensively diffused. It is erroneous to imagine that it does not matter how money is expended, whether productively or unproductively, provided it gives labour to the people, or provided the money expended remains at home; for while in the one case the object produced remains, and, like capital, becomes serviceable for

further production, in the other the object produced is either useless or utterly wasted. What is expended productively is never consumed. It reproduces itself again and again. What is expended unproductively is lost. It is the same whether the expenditure is public or private. It is the same whether it is devoted to maintain men or to maintain things. It is the same whether the money is lent to the home Government or to foreign countries. Let money be lent to be expended in wars, it is utterly wasted. Let money be judiciously expended for railways or canals, or for drainage or other productive purpose, and it remains a source of wealth and prosperity. Your Committee have limited their observations to the appropriation of wages and other income. They might have illustrated the question with the employment of the human forces and with the appropriation of time, the most valuable of human property. Idle habits and an unnecessary number of holidays likewise restrict the productive power of the nation, and rob the same of much of its resources. England labours much and she expends liberally. It is the duty of the nation to use aright its hard-won gains, so that they may minister to the comfort and affluence of the people.

Consumption of Tea and Sugar.

In a paper laid before Parliament in 1857 on the consumption of tea and sugar in the United Kingdom (184, Sess. 2) there is a report by Sir Charles Pressly, of the Inland Revenue, giving the result of an inquiry made through the excise officers into the proportionate quantities of tea and sugar consumed by the upper, middle, and lower classes in England and Scotland respectively, which were as follows:—

Tea.

	England Per cent.	Scotland Per cent.	Great Britain Per cent.
Upper classes	18	15½	17½
Middle classes	38	38½	38
Working classes	44	46	44½
	100	100	100

Sugar.

	England	Scotland	Great Britain
Upper classes	23	22	22½
Middle classes	37	40	38
Working classes	40	38	39½
	100	100	100

Since 1857, however, the condition of the working classes has considerably improved, and there is reason to believe that their proportion of consumption is fully 66 per cent. of the whole.

Estimate of Gross or Personal Expenditure.

(The Italics indicate articles of luxury.)

	Total	Working Classes		Middle and Higher Classes	
		Amount	Per cent. of Total	Amount	Per cent. of Total
Food and Drink:—	£	£		£	
Bread	77,500,000	50,800,000	66	26,700,000	34
Potatoes	33,200,000	22,000,000	66	11,200,000	34
Vegetables	17,000,000	11,200,000	66	5,800,000	34
Meat	99,800,000	50,000,000	50	49,800,000	50
Fish	14,500,000	8,700,000	60	5,800,000	40
Butter and Cheese	36,000,000	21,600,000	60	14,400,000	46
Milk and Eggs	42,000,000	16,800,000	40	25,200,000	60
Fruit	11,100,000	3,300,000	30	7,800,000	70
Sugar	27,000,000	17,800,000	66	9,200,000	34
Tea	15,300,000	10,100,000	66	5,200,000	34
Coffee	3,000,000	—	—	3,000,000	100
Beer	75,000,000	56,200,000	75	18,800,000	25
Spirits	40,000,000	30,000,000	75	10,000,000	25
Wine	9,000,000	900,000	10	8,100,000	90
	500,400,000	299,400,000	60	201,000,000	40
Dress:—					
Cotton	31,000,000	15,500,000	50	15,500,000	50
Wool	63,000,000	31,500,000	50	31,500,000	50
Linen	7,700,000	800,000	10	6,900,000	90
Silk	17,600,000	1,800,000	10	15,800,000	90
Leather	23,500,000	11,700,000	50	11,800,000	50
Silver Plate & Jewellery	5,000,000	500,000	10	4,500,000	90
	147,800,000	61,800,000	42	86,000,000	58
House:—					
House-rent	71,700,000	28,700,000	40	43,300,000	60
Furniture	11,000,000	2,200,000	20	8,800,000	80
Coal	15,000,000	6,000,000	40	9,000,000	60
Gas	13,700,000	1,400,000	10	12,300,000	90
Water	5,000,000	1,000,000	20	4,000,000	80
	116,400,000	39,300,000	35	77,100,000	65
Tobacco	13,100,000	9,200,000	70	3,900,000	30
Education	11,000,000	1,100,000	10	9,900,000	90
Literature	7,000,000	1,400,000	20	5,600,000	80
Newspapers	5,000,000	500,000	10	4,500,000	90
Church	12,000,000	1,200,000	10	10,800,000	90
	35,000,000	4,200,000	12	30,800,000	88
Locomotion	7,000,000	1,000,000	14	6,000,000	86
Theatres	6,500,000	1,000,000	15	5,500,000	85
Amusements	6,000,000	900,000	15	5,100,000	85
	12,500,000	1,900,000	15	10,600,000	85
Taxes	47,500,000	4,700,000	10	42,800,000	90
Total	879,700,000	421,500,000	48	458,200,000	52

Estimate of Net or National Expenditure.

	Total	Working Classes		Middle and Higher Classes	
		Amount	Per cent. of Total	Amount	Per cent. of Total
Food and Drink:—	£	£		£	
Bread	60,000,000	39,600,000	66	20,400,000	34
Potatoes	27,700,000	17,800,000	66	9,900,000	34
Vegetables	14,000,000	9,200,000	66	4,800,000	34
Meat	83,000,000	41,500,000	56	41,500,000	50
Fish	17,700,000	7,000,000	60	4,700,000	46
Butter and Cheese	30,000,000	18,000,000	60	12,000,000	46
Milk and Eggs	35,000,000	14,000,000	40	21,000,000	66
Fruit	9,300,000	2,700,000	30	6,600,000	70
Sugar	24,700,000	19,300,000	66	5,400,000	34
Tea	8,800,000	5,800,000	66	3,000,000	34
Coffee	2,200,000	—	66	2,200,000	100
Beer	29,000,000	21,700,000	75	7,300,000	25
Spirits	8,000,000	6,000,000	75	2,000,000	25
Wine	5,800,000	600,000	10	5,200,000	90
	349,200,000	203,200,000	58	146,000,000	42
Dress:—					
Cotton	25,8 0,000	12,900,000	50	12,900,000	50
Wool	52,800,000	26,400,000	50	26,400,000	50
Linen	6,400,000	600,000	10	5,800,000	90
Silk	14,700,000	1,500,000	10	13,200,000	90
Leather	19,600,000	9,800,000	50	9,800,000	50
Silver Plate & Jewellery	4,000,000	400,000	10	3,600,000	90
	123,300,000	51,600,000	42	71,700,000	58
House:—					
House-rent	67,400,000	27,000,000	40	40,400,000	60
Furniture	9,000,000	1,800,000	20	7,200,000	80
Coal	12,000,000	4,800,000	40	7,200,000	60
Gas	11,000,000	1,100,000	10	9,900,000	90
Water	4,000,000	800,000	20	3,200,000	80
	103,400,000	35,500,000	34	67,900,000	66
Tobacco	3,000,000	2,100,000	70	900,000	30
Education	2,200,000	200,000	10	2,000,000	90
Literature	5,000,000	1,000,000	20	4,000,000	80
Newspapers	3,500,000	400,000	10	3,100,000	90
Church	2,400,000	200,000	10	2,200,000	90
	13,100,000	1,800,000	14	11,300,000	86
Theatres	1,600,000	200,000	15	1,400,000	85
Amusements	1,500,000	200,000	15	1,300,000	
	3,100,000	400,000	15	2,700,000	85
Locomotion	3,000,000	400,000	14	2,600,000	86
Taxes	7,000,000	700,000	10	6,300,000	90
Cost of Distribution	77,500,000	36,000,000	12	41,500,000	88
Total	682,600,000	331,700,000	49	350,900,000	51

Report of the Committee, consisting of Mr. JAMES HEYWOOD, Mr. WILLIAM SHAEN, Mr. STEPHEN BOURNE, Mr. ROBERT WILKINSON, *the* Rev. W. DELANY, Professor N. STORY MASKELYNE, Dr. SILVANUS P. THOMPSON, Miss LYDIA E. BECKER, Sir JOHN LUBBOCK, Professor A. W. WILLIAMSON, Mrs. AUGUSTA WEBSTER, Dr. H. W. CROSSKEY, Professor ROSCOE, Professor G. CAREY FOSTER, *and* Dr. J. H. GLADSTONE, *(Secretary), appointed to watch and report on the workings of the proposed revised New Code, and of other legislation affecting the teaching of Science in Elementary Schools.*

WHEN this Committee was reappointed at York, it was with a special view to the important changes which it was expected the Government would make in the Education Code. In the postscript to their previous report, great satisfaction was expressed at the general scope of the 'proposals' that had just been submitted to Parliament, but it was urged that the knowledge of nature should be more effectually encouraged as a class subject.

On assembling in the autumn, your Committee added to their number the Rev. H. W. Crosskey of Birmingham, and Professor Roscoe of Manchester, and, subsequently, Professor G. Carey Foster of London.

At the first meeting it was determined to enter into communication with Mr. Mundella, the Vice-President of the Committee of Council on Education, but the serious illness of that gentleman caused a delay. The Secretary, however, eventually saw him at his own house, and found him desirous of receiving the views of the Committee by deputation. As this was a step which your Committee felt themselves not justified in taking unless through the governing body of the Association itself, they drew up a series of resolutions, and submitted them to the Council, with the request that that body should appoint a deputation to urge their views.

These resolutions were passed by the Council, with the addition of that numbered VII. They were as follows:—

I. That Clauses 9 (3), 20, 26, and the Standard work in Geography (pp. 6 and 7) be approved.

II. That the arrangements involved in Clauses 18, 19, 21, 23, and 27 be subject to revision on the following grounds:—

a. That Clauses 19 and 21, read together, will practically exclude Elementary Science teaching in the Lower Division, as Geography will be almost always chosen by teachers as the second subject.

b. That placing Standard IV. in the Lower instead of the Upper Division will restrict the choice of Class-subjects to be taught in that Standard, and altogether exclude the teaching of any of the Specific subjects.

c. That, taking all these Clauses as they stand, there will practically be a cessation in the teaching of Elementary Science from the time of leaving the Infant School (Clause 9 (3)), till entering the Upper Division (Clauses 23 and 27).

It is therefore recommended that Clause 21 be left out; and that Clause 19 be so modified as to permit of the ordinary Class Grant being

paid if the children pass in any one or two of the Class-subjects, and an additional Grant if three be taken.

III. That the list of Specific subjects (Clause 25) should include Elementary Physics, and the fundamental facts of Chemistry; and the word 'Geometry' should be used instead of 'Euclid.'

IV. That Clause 29 be left out, inasmuch as Domestic Economy includes the principles of alimentation, sanitation, &c.

V. That the teaching of Specific as well as Class-subjects in Night Schools should be provided for in Clause 30.

VI. That the Standard work in Elementary Science (pp. 6 and 7) needs rearranging:—

The division (*a*) should generally include plants as well as animals.

The divisions (*b*) and (*c*) should be welded together, and more progressively arranged.

VII. That the Science programme should be regarded as a suggestion, but not necessarily as an inevitable arrangement.

VIII. That the Pupil Teachers' course (p. 11) should provide for the study by them of Elementary Science, seeing that they will in all probability be required to give Object lessons, or to teach Elementary Science in the Schools, and to attend science classes at College.

A deputation was appointed to present the memorial, but so many other public bodies were approaching the Education Department on the subject of the New Code, that Lord Spencer was unable to find time to receive it, and the memorial was sent in the usual way. Dr. Gladstone, however, as one of a deputation from the London, Birmingham, and other School Boards, had an opportunity of urging the claims of Science, and of mentioning the special wishes of the British Association. Nothing could be more distinct than the assurance of both Lord Spencer and Mr. Mundella as to their desire to introduce the teaching of Elementary Science as far as circumstances would permit.

Recommendations somewhat similar to those of the British Association were made, not only by the above School Boards, but also by a Conference of leading educationists on Code Reform, and by the British and Foreign School Society.

When the New Code was laid on the table of the House, on March 6, it appeared that some of these recommendations had been adopted, and that all the clauses in the 'Proposals' which were approved by your Committee had been retained.

The proposals thus retained are as follows:—

In Infant Schools the merit grant will be dependent upon the report of the Inspector, who will have to take into consideration the provision made for 'simple lessons on objects, and on the phenomena of nature and of common life.'

The leading facts of Physical Geography will be taught, not, as before, as an optional specific subject for the high standards, but as a part of Geography, which is a class-subject for the children in all the standards.

The teaching of the principles of Agriculture as a specific subject is, for the first time, recognised.

The recommendations adopted are as follows:—

'Chemistry' and 'Physics' in the two branches of 'sound, light, and heat,' and of 'electricity and magnetism,' have been added to the list of sciences capable of being taken up as specific subjects by children in Standards V., VI., and VII.

The scientific specific subjects are admitted for the first time into the curriculum of Evening Schools.

The Department has considerably modified its scheme as to 'Elementary Science' as a class-subject; this 'may be framed so as to lead the scholars in Standards I. to IV. up to one of the scientific specific subjects;' but a scheme is also given which 'may be taken as a guide suggesting heads for a sufficient number of lessons in each standard.' In the scheme plants are recognised as fully as animals, and the inconsistencies that occurred in the original scheme are avoided.

The Department has not, however, acceded to other recommendations of your Committee. There are still retained such restrictions as will greatly hinder the introduction of this elementary science as a class subject. Domestic Economy has lost its preference as a specific subject in girls' schools. Euclid is still enforced as the handbook of geometry. There is no provision for the examination of pupil-teachers by Her Majesty's Inspector in any branch of natural science, excepting that geography is made to include a good deal of physical knowledge.

Your Committee having been informed that Sir John Lubbock intended to move in Parliament that it was desirable to allow children to be presented for examination in any of the recognised class-subjects, passed a resolution offering him 'their support in asking that the three class-subjects of Schedule II. of the New Code, viz., English, Geography, and Elementary Science, should be placed on the same footing.' Sir John Lubbock, in his speech, referred to the views of the British Association on this point; the debate which ensued was very favourable to the claims of Elementary Science, and the Vice-President promised to give the subject further consideration, and to 'submit it to the Council of Her Majesty's Inspectors and the able men who assisted him in framing the Code, and, if it was possible, he should be happy to yield to the wishes which had been expressed.' [1]

Many of the Elementary Schools of this country are now working under the New Code, and before the month of May, 1883, they will all be in that condition. In that month also, the Government inspection under this Code will commence, and it will be possible to ascertain many points of interest, such as (1) the quality of the object-lessons in the Infant Schools ; (2) how far the proposed improvements in the teaching of geography are carried out in practice; (3) to what extent Elementary Science is taken up as a class-subject, and whether the teachers generally take it up as an introduction to the scientific specific subjects, or continue it as a class-subject throughout the school; and, if so, whether they have adopted some fuller scheme than that suggested in the Second Schedule; (4) whether the discontinuance of the teaching of specific subjects in Standard IV. is really a gain or a loss to science.

Your Committee, if reappointed, propose to obtain information on these points; and to draw the attention of the Council to any matters that may be necessary in connection with the working of the Code, or in respect of any future alterations.

[1] See *Times*, April 4, 1882.

Report of the Committee, consisting of Sir FREDERICK BRAMWELL (*Secretary*), Professor A. W. WILLIAMSON, Professor Sir WILLIAM THOMSON, Mr. ST. JOHN VINCENT DAY, Dr. C. W. SIEMENS, Mr. C. W. MERRIFIELD, Dr. NEILSON HANCOCK, Mr. F. A. ABEL, Captain DOUGLAS GALTON, Mr. E. H. CARBUTT, Mr. E. MACRORY, Mr. H. TRUEMAN WOOD, Mr. W. H. BARLOW, *and* Mr. A. T. ATCHISON, *appointed for the purpose of watching and reporting to the Council on Patent Legislation.*

THE Committee have no actual progress in Patent Legislation to report. The Bill promised in the Queen's Speech, and, as was stated by Mr. Chamberlain, to be prepared by the Board of Trade, was not even introduced.

Two Bills for the reform of the Patent Law were brought in during the Session by private members. One of these was by Mr. Anderson, and was generally similar to the Bills brought in by the same gentleman in 1880 and in 1881 (*see* 'B. A. Reports,' 1880, p. 318, and 1881, p. 222), but contains one important alteration. It provides an examination into the novelty of the invention, with the object apparently of giving friendly advice to the patentee. Mr. Anderson has also materially modified in this year's Bill the schedule of fees to be paid. This Bill was only read a first time.

The second of the two Bills was the one prepared by the Society of Arts, and fully described in the last report of this Committee (*see* 'B. A. Report,' 1881, p. 222). It was introduced by Sir John Lubbock, Mr. W. H. Smith, and Mr. J. C. Lawrance, Q.C. It was read a first time on March 15, and a second time on April 28, Sir John Lubbock stating, on the latter occasion, that should the House assent to the second reading of the Bill, he would defer further action, in order to move that the Bill should be referred to the same Committee to which it was understood the Government Patent Bill, when introduced, would be referred. As above stated, the Government measure never saw the light at all, and consequently no further progress was made with the Society of Arts Bill. The Council of that Society announce in their annual report that they will endeavour to bring the Bill forward again next year.

Most of the provisions of the Bill as introduced are identical with those of the original draft, an abstract of which was given in the report of this Committee last year. Consequent, however, upon the public discussion of the Bill, the Society of Arts made certain alterations in some of their original proposals. The fees were slightly reduced, and the definition of 'subject-matter' was modified. The most important change, however, referred to the proposed method of trying Patent actions. The new Court, which the Bill as first drafted set up for this purpose, disappeared from the Bill in its final shape, and in place of this provision was inserted one by which the Commissioners of Patents (to be appointed under the Bill) would be empowered to act as assessors, or as referees, or as arbitrators, under certain specified conditions.

It may be worth noting that the Bill had the advantage of being introduced by the President of the Association, while the President-elect

(Dr. Siemens) is one of the Society of Arts Committee which prepared the Bill.

The Committee request that they may be reappointed, and that the grant made to them in 1880 of 5*l.* may be renewed.

Report of the Committee, consisting of Sir JOSEPH WHITWORTH, Dr. C. W. SIEMENS, Sir FREDERICK BRAMWELL, Mr. A. STROH, Mr. BECK, Mr. W. H. PREECE, Mr. E. CROMPTON, Mr. E. RIGG, Mr. A. LE NEVE FOSTER, Mr. LATIMER CLARK, Mr. BUCKNEY, *and* Mr. H. TRUEMAN WOOD *(Secretary), appointed for the purpose of determining a Gauge for the manufacture of the various small screws used in Telegraphic and Electrical Apparatus, in Clockwork, and for other analogous purposes.*

1. THIS Committee was formed by the General Committee of the British Association assembled at York in August and September, 1881, for the purpose of determining a gauge for the manufacture of the various small screws used in telegraphic and electrical apparatus, in clockwork, and for other analogous purposes.

2. At that meeting a paper was read by Mr. Preece pointing out the desirability of establishing such a gauge. Although the Whitworth gauge is almost invariably adopted for the bolts and screws used in mill-work and engineering in England, no general system has been hitherto applied to the smaller screws used either in clockwork, philosophical instrument work, or in the numerous practical applications of electricity that are now rapidly becoming so important. In fact, at the present time gauges and screw plates almost equal in number the makers engaged in the trade. One instance was brought to the attention of the Committee by a manufacturer who had to execute an order for railway signal apparatus in accordance with three sample instruments containing among them twenty-one screws of different threads, not one of which happened to be in use in his shop. There is now no recognised form of thread, no specified number of threads per inch—in fact, no generally accepted gauge based on practice and experience. Great inconvenience is felt in providing for repairs, which are in consequence more costly and less efficient.

The employment of some coherent and uniform system is manifestly required. It not only would render repairs easier, speedier, and cheaper, but it would introduce interchangeability of parts, and further the extension of piecework; and it would reduce the equipment of workshops with special and costly tools.

3. The subject of uniformity in screws has been very warmly taken up by the Société des Arts de Genève, which appointed a Committee in December 1876, who after assiduous labours issued a report in 1878. The system proposed by them has been very fully described by Professor Thury in two pamphlets published in Geneva.[1] The Committee collected numerous screws of all sizes from many factories, measured them care-

[1] *Systématique des vis Horlogères*, Geneva, 1878. *Notice sur le Système des vis de la Filière Suisse*, Geneva, 1880.

fully, tabulated their several dimensions, and plotted the results by the ordinary method of linear co-ordinates. They determined the mathematical equations to curves that most closely corresponded with the ratios of diameter to pitch thus found to have been employed in practice, and adopted the one which most nearly represented the mean average proportions of the screws in use at various shops and in different countries.

The Swiss Committee took 1 millimetre pitch as the basis of their system. It was agreed that such a pitch was best adapted to a screw having a diameter of 6 millimetres. The form of thread adopted was triangular, the angle made by producing the two sides being approximately $47\frac{1}{2}°$; the depth being $\frac{3}{5}$ of the pitch, the top being rounded off by a radius $\frac{1}{6}$ and the bottom by a radius $\frac{1}{5}$ of the pitch.

The Committee has had an opportunity of examining screw-plates and numerous packets of the corresponding screws manufactured on this system.

The following table gives the pitches and diameters in millimetres and 'mils'[1] to two significant figures, and the number of threads per inch of all the screws comprised in the small screw series, which happens to cover the exact ground to which the attention of the Committee has been specially directed, namely, diameters below the $\frac{1}{4}$-inch.

Table of Swiss Screws.

No.	Pitch		Diameter		Threads per inch
	Mm.	Mil.	Mm.	Mil.	
25	0·072	2·8	0·25	10	357
24	0·080	3·1	0·29	11	323
23	0·089	3·5	0·33	13	286
22	0·098	3·9	0·37	15	256
21	0·11	4·3	0·42	17	233
20	0·12	4·8	0·48	19	208
19	0·14	5·3	0·54	21	189
18	0·15	5·9	0·62	24	170
17	0·17	6·6	0·70	28	152
16	0·19	7·3	0·79	31	137
15	0·21	8·1	0·90	35	124
14	0·23	9·0	1·00	40	111
13	0·25	10·0	1·2	46	100
12	0·28	11·	1·3	52	91
11	0·31	12·	1·5	59	83
10	0·35	14·	1·7	67	71·4
9	0·39	15·	1·9	76	66·7
8	0·43	17·	2·2	86	58·8
7	0·48	19·	2·5	97	52·6
6	0·53	21·	2·8	111	47·6
5	0·59	23·	3·2	126	43·5
4	0·66	26·	3·6	142	38·5
3	0·73	29·	4·1	162	34·5
2	0·81	32·	4·7	183	31·2
1	0·90	35·	5·4	208	28·6
0	1·00	39·	6·0	236	25·6

[1] The 'mil' is the thousandth part of the British inch.

It is to be observed that the numbers by which the screws are designated, given in the first column, are not arbitrary. Each pitch of the series is $\frac{9}{10}$ths of that which succeeds it in the table.

Thus the several pitches are:—

$$1 \text{ mm.}; \ \frac{9}{10} \text{ mm.}; \ \left(\frac{9}{10}\right)^2 \text{mm.}; \ \left(\frac{9}{10}\right)^3 \text{mm.}; \ \ldots \ \left(\frac{9}{10}\right)^n \text{ mm.}$$

This series may be expressed in the form:—

$$0{\cdot}9^0; \ 0{\cdot}9^1; \ 0{\cdot}9^2; \ 0{\cdot}9^3; \ \ldots \ 0{\cdot}9^n; \ldots \quad (1)$$

whence it is at once evident that the designating number of a screw is the index of the power to which 0·9 must be raised in order to ascertain its exact pitch in millimetres.

The method by which the relation between pitch and diameter is arrived at will be gathered from the following explanation:—

Let D represent the diameter and P the pitch. Then, generally,

$$D = f(P)$$

Evidently there can be no constant term, for when $D = O$, P must also $= O$. Moreover, D, practically cannot be a simple multiple of P, for experience has shown that small screws must have a less number of threads per diameter than large screws.

Hence the formula will be of the form

$$D = m P^k \quad . \quad . \quad . \quad (2)$$

where m and k are constants to be determined.

Since 1^k is 1 whatever be the value of k, it follows that the coefficient m represents the value of D when P is 1. The Swiss Committee agreed that the unit pitch (1 millimetre) should be adopted for the screw having a diameter of 6 millimetres; in other words they make $m = 6$.

The value of k must be ascertained by trial.

$k = 1$ would give a constant ratio, which we know is inadmissible.

$k = 2$ will be found on trial to give a far too rapid decrease in the ratio of diameter to pitch.

The several simple fractions between these limiting values were tried in succession, and the results obtained when using $\frac{6}{5}$ were found to give results that best accord with practice and experience.

Substituting the values thus arrived at in (2), the formula becomes

$$D = 6P^{\frac{6}{5}} \quad . \quad . \quad . \quad (3)$$

The Swiss system is thus very complete, but there are reasons which prevent this Committee from recommending its adoption in its entirety.

4. No one has done more to establish gauges of all kinds in England than Sir Joseph Whitworth. His classical paper on 'An uniform system of screw threads' was communicated as far back as 1841 to the Institution of Civil Engineers. He had made an extensive collection of screw-bolts from the principal workshops throughout England, and the average thread was carefully measured for different diameters. The $\frac{1}{4}$, $\frac{1}{2}$, 1, and $1\frac{1}{2}$ inches were selected and taken as the fixed points of a scale by which the intermediate sizes were regulated. The result is an admirable thread for the large iron bolts and screws used in fitting up steam-engines and other machinery. The angle made by the sides of this thread is 55°. One-sixth of the depth of the thread is rounded off from the top, and one-sixth from the bottom. The actual depth is rather more than three-fifths, and less than two-thirds, of the pitch.

The slow adoption of such an admirable system was perhaps due, in great measure, to the fact that it was put forward by an individual and not by an Association. A single individual, however exalted his reputation, cannot secure that immediate and universal attention which is obtained by such an organisation as the British Association. The system of units of electrical measurements sanctioned by the Association obtained instant recognition, and has now, thanks to the Congress of Electricians held in Paris in October 1881, become universally accepted. It is hoped that the same result will follow the recommendations of this Committee.

5. The question of the introduction of the metrical system occupied the serious consideration of the Committee, but, considering the fact that it is not generally adopted in engineering or manufacture in England, and that it is as yet little understood by our workmen, it was thought better to suggest no change in this direction. The Committee is not insensible to the simplicity of the metrical system and to its possible universality, nor to the fact of its gradual introduction in scientific circles; but while the manufacturing interests are still wedded to the British inch and its multiples and sub-multiples, and while the British legal standard of length is still the yard, the Committee has felt it impossible to suggest a change which has little chance of adoption, and which might jeopardise the introduction of that with which they are more concerned—viz., a uniform screw-thread.

Hence it was determined that the unit of length taken should be the 'mil,' and that the decimal system should be adopted for expressing dimensions.

6. The use of a screw is to draw together and to unite certain parts of apparatus in firm and intimate contact. To attain these ends a screw must facilitate the application of mechanical power to draw the parts together, and it must possess strength to hold them so; it must not interfere with the easy separation of these united parts when necessary; it must possess durability—that is, it must be capable of repeated use without undue friction and without wear, otherwise it will speedily become loose and dangerous when frequently removed and restored. There has to be considered the pitch of the screw, its relation to the diameter of the bolt on which it is cut, the depth of the cut, and the form of the thread. The pitch primarily determines the power of the screw, for it determines, for each diameter, the angle of the inclined plane; the depth determines the section of core left to resist shear or rupture; while the form of the thread determines the durability and efficiency, and determines also the surface of thread to bear endway strain.

7. The Committee have devoted very considerable attention to the pitch, form, and depth of screws, and they have compared together a large number of different kinds, some of which are in actual use, while others have only been suggested. They have, moreover, decided on recommending the adoption of the Whitworth form of thread, not only because it is so well known, but because experience has proved it excellent and unsurpassed when employed for engineers' bolts. The Committee, however, are not unanimous on all questions involved by this proposal, and as there are several points that require to be thoroughly sifted and tested, they ask to be reconstituted and to be allowed a small grant to put their proposal to the test of practice, and to have a few gauges constructed for distribution or examination.

Report of the Committee, consisting of Mr. JAMES GLAISHER, Mr. C. W. MERRIFIELD, Sir FREDERICK BRAMWELL, Professor O. REYNOLDS, Professor W. CAWTHORNE UNWIN, Mr. ROGERS FIELD, Mr. T. HAWKSLEY, *and* Mr. A. T. ATCHISON (*Secretary*), *appointed to consider and report upon the best means of ascertaining the effective Wind Pressures to which buildings and structures are exposed.*

THE total pressure on small plane surfaces due to actual winds in high and exposed positions has to a great extent been ascertained with sufficient accuracy for engineering purposes, and the relation between the pressure and the velocity on flat plates is also known with accuracy enough to make the observations with velocity anemometers available in estimating the probable maximum pressure in such exposed positions as are chosen for the placing of anemometers.

It must be assumed for the present at least, that for engineering purposes, pressures of 80 lbs. or even 90 lbs. per square foot on small surfaces have been correctly recorded in extremely exposed positions such as the Bidston Observatory, while pressures approaching the limit prescribed by the Board of Trade (56 lbs. per square foot), may possibly act on engineering structures in exposed positions.

In applying these data to engineering structures the question arises whether their form, size, and exposure is so different from a thin anemometer plate that the effective pressures to which they are subject cannot be deduced from the latter.

To answer this question inquiries on the following points appear necessary.

i. The law of the distribution of the pressure of a fluid impinging on a surface.

ii. What is the relation of the direct front pressure and the negative pressure produced by the formation of a partial vacuum behind the plate due to the gradual curvature of the fluid stream lines in passing an obstacle.

iii. What is the law of variation of pressure with increase of area of surface.

iv. What is the law of variation of pressure with increase of elevation above the ground surface.

v. How far the form of actual engineering structures diminishes the front or back pressure which would be experienced by a flat plate similarly placed.

There seems reason to believe that the maximum direct pressure on a surface due to fluid impinging on it at a velocity v is $\frac{Gv^2}{2g}$ when G is the weight of a cubic unit of the fluid. From the point where the pressure is greatest the intensity must diminish towards the edges, where it may possibly even become negative (or less than the barometric pressure), but the law of variation is almost entirely unknown, and requires investigation by direct experiment.

Further, the total pressure registered by an anemometer plate is made up of the direct pressure which, from what has been said above, cannot exceed the area multiplied by $G\frac{v^2}{2g}$ and a negative pressure at the back

of the plate the whole amount of which is imperfectly known, and about the distribution of which nothing has yet been ascertained.

The total observed pressure on a thin plate of small size is somewhere in value between $1\cdot4\ G\ A\frac{v^2}{2g}$ and $2\ G\ A\frac{v^2}{2g}$ where A is the area of the plate, which appears to show (1) that on a small plate the variation of pressure is not very great, and (2) that the negative pressure approaches to at least one-half the front pressure.

The Committee consider that observations might usefully be made to throw light upon some of these points, and they suggest that as with the velocities under consideration, the pressures of air in motion probably follow approximately the laws of the pressure of water in motion, experiments should first be made in running water.

A steady flowing river affords a current of fluid moving with fairly uniform motion at a definite and readily measurable velocity, while the pressures of a stream of water are much more easily measured than those of an air current. Hence the determination of the pressures at different points of the front and back of a plate immersed in a river could be easily made, and would establish the law of distribution applicable to any fluid, to wind as well as water.

Further, the influence of the form of the obstacle on the pressure produced by the stream could be readily determined, the extent to which one body would be sheltered by another placed at various distances above it could be observed, and the total pressures on such structures as a girder or a pair of girders placed a short distance apart at right angles to the stream could be measured.

Respecting the law of the variation of pressure with increase of area, the older French experiments give conflicting results, the pressure in some cases being found to increase more rapidly and in others less rapidly than the area, while White, by a comparison of the observed and calculated heel of ships under sail, has arrived at the conclusion that the former is the case. As to experiments on this point we have no recommendation to make, but we believe that the observations now being carried on with a pressure plate of 300 square feet in area by Messrs. Fowler and Baker, at the site of the proposed Forth Bridge, will give much useful information.

As to the increase of pressure at different elevations above the surface of the ground, which is of special importance in the consideration of engineering structures, we recommend that experiments should be made by placing anemometers at various heights, supported by a lofty chimney or other isolated structure.

It would appear of the highest importance to engineers that some data should be available to enable them to determine the influence of the exposure of a structure.

As in the design of marine works the depth of water and the length of fetch enable some estimate to be made of the strength of structure required to withstand the heaviest seas to which they may be exposed, so a careful comparison of the wind pressures observed during the height of a gale at various stations where anemometers exist with any standard within the track of the gale, would enable some estimate of the relative exposure of similar places to be made.

Exceptionally high gusts of short duration should be excluded from the comparison, as being probably limited in area.

On the Boiling Points and Vapour Tension of Mercury, of Sulphur, and of some Compounds of Carbon, determined by means of the Hydrogen Thermometer. By Professor J. M. CRAFTS.

[A communication ordered by the General Committee to be printed *in extenso* among the Reports.]

A HYDROGEN thermometer, in preference to an air thermometer, was adopted, because the more rapid flow of hydrogen through a capillary tube permits the use of one of smaller dimensions than when air is taken. A new form of constant-volume thermometer was used, in which an electric contact between the mercury in the manometer and a platinum point causes a current to excite a magnet, and close a cock to arrest the flow of mercury into the manometer tube at the moment that the gas attains a fixed volume, determined by the surface of the mercury touching the platinum point.

The advantages secured by the system are the reduction of the observations of the mercury level to one, instead of two; the possibility of diminishing the size of thermometer bulb from 200–500 cc. to 1–10 cc.; and the rapidity of action due to the automatic movement of the instrument.

The calculation of results has been facilitated by the compilation of an extended series of tables.

The boiling point of mercury was redetermined with an apparatus similar to that used for taking the boiling point of water; and the chief causes of error, which Regnault noticed regarding his own experiments, have been removed. It is proposed to use boiling mercury, like water, to fix an additional fundamental point in thermometry.

Mercury boils at 357·0 under a barometric pressure of 760 millimetres.

Sulphur boils at about one degree lower than the temperature given by Regnault, and can be used to fix temperatures near 444°.

Two other substances were found well adapted to obtain constant temperatures near 200 and 300 Centigrade, and the means of purifying them were carefully studied. Naphthaline, when pure enough to melt at 79·6–79·9, does not vary more than 0·1° from the boiling point 218·06, bar. 760· mm. Benzophenone prepared by the action of oxychloride of carbon upon pure benzine in the presence of chloride of aluminium, when pure enough to melt at 47°·7–48°·0, boils at 306°·1, bar. 760 mm.

The boiling points of these two substances were determined under pressures varying from 87 to 2,300 mm., giving a series of temperatures that can be easily established and maintained for any length of time. The range of temperature is from 140° to 350°.

It is very probable that benzine may also be easily obtained with a perfectly fixed boiling point, and it is intended to study the properties of benzine purified by fractional crystallisations on a large scale. When perfectly pure fragments of solidified benzine are allowed to melt with the precautions usual in a zero-point determination, a delicate thermometer only sinks from 5·17 to 5°·16 during the fusion. The product studied by Regnault melted at 4·45, and was impure.

The boiling points of the following carbon compounds are grouped to show that some of these experiments point to the conclusion that successive, similar, additions to the molecular weight do not cause the boiling

points to rise by a constant quantity, as supposed by Kopp, but that in a large number of cases the increments to the boiling temperatures diminish by a constant amount. Where such a series has been established the three columns of the tables contain, respectively, the boiling points for a barometric pressure of about 725 mm., the differences between these numbers, and the nearly constant diminution of the differences.

Bar. 725 mm.	Boiling point	1st difference	2nd difference
Toluine, $CH_3\,C_6H_5$	109°		
		153°	
Diphenyl methane, $CH_2\,(C_6H_5)_2$	262°		64°
		89°	
Triphenyl methane, $CH\,(C_6H_5)_3$	351°		64° ?
		25° ?	
*Tetraphenyl methane, $C\,(C_6H_5)_4$	376° ?		

Bar. 775 mm.	Boiling point
Hydrocarbon from Toluene red, $C_{21}H_{20}$	360°–363°
Hydrocarbon from Xylidine red, $C_{22}H_{22}$	377°

Bar. 717 mm.	Boiling point	1st difference	2nd difference
Benzine, C_6H_6	78°·5		
		173°·5	
Diphenyl, $C_6H_5\,C_6H_5$	252°		46°·5
		127° ?	
*Diphenyl benzine, ? $C_6H_4\,(C_6H_5)_2$?	379° ?		46°·5
		80°·3	
Triphenyl benzine, $C_6H_3\,(C_6H_5)_3$	459°·3		

Bar. 725 mm.	Boiling point	1st difference	2nd difference
Benzine, C_6H_6	78°·5		
		137°·5	
Naphthaline, $C_{10}H_8$	216°		18°·5
		119°	
Phenanthrene, $C_{14}H_{10}$	335°		17°·5
		101°·5	
Chrysine, $C_{18}H_{12}$	436°·5		18°·
		83°·5	
Picine, $C_{22}H_{14}$	520°		

Pyrine (Phenyline Naphthaline), bar. 723·7 mm., boiling point 391°·8
Anthracine, $C_{14}H_{10}$, bar. 721·6 mm., boiling point 341°
Anthraquinone, $C_{14}H_8O_2$, bar. 723·5 mm., boiling point 374°

*The boiling points of tetraphenyl methane and of diphenyl benzine are hypothetical; these bodies have not been studied.

Benzophenine, $CO\,(C_6H_5)_2$, bar. 720 mm., boils 303°·5
Difference 73°
Sulphobenzide, $SO_2\,(C_6H_5)_2$, bar. 720 mm., boils 376°·5
Monochlorated sulphobenzide SO_2, C_6H_5, C_6H_4Cl, bar. 719 mm., boils 389°
Sulphotoluide, $SO_2\,(C_7H_7)_2$, bar. 714 mm., boils 405°
Durol ketone, $CO\,(C_{10}H_{14})_2$, bar. 724 mm., boils 342°–343°
Phenyline sulphide $(C_6H_4S)_2$, bar. 716·8 mm., boils 358°·8
Carbazol, bar. 730·8 mm., boils 350°
Base from Anthracine blue, bar. 724 mm., boils 445°·5
Phenyl naphthyl amine, $NH\,(C_{10}H_7)\,(C_6H_5)$, bar. 720 mm., boils 395°·5
Hexa-methyl benzine, $C\,(CH_3)_6$, bar. 752, boils 262°·2–264°·4

NOTE.—The above communication is little more than an abstract of that made by the author, by word of mouth, at the meeting of the Association, as, from unavoidable circumstances, he has been unable to prepare the whole of his manuscript for publication in time for the present volume.

On the Method of Harmonic Analysis used in deducing the Numerical Values of the Tides of long period, and on a Misprint in the Tidal Report for 1872. *By* G. H. DARWIN, *M.A.*, *F.R.S.*

[A communication ordered by the General Committee to be printed *in extenso* among the Reports.]

I HAVE recently been carrying out a laborious reduction by the method of Least Squares of the observations of the tides of long period at a number of stations. The results, which seem to have an important bearing on the question of the rigidity of the earth's mass, will appear as § 848 in the new edition of Thomson and Tait's 'Natural Philosophy,' now in the press.

Subsequently to the completion of the calculations Professor J. C. Adams discovered a misprint in the Tidal Report of 1872, which forms the basis for the method of harmonic analysis which has been applied to the tidal observations.

On inquiring of Mr. Roberts, who has superintended the original computations, Professor Adams learnt that the erroneous formula has been used in all the reductions of the long-period tides.

It now therefore becomes necessary to investigate the amount of error which may have been incurred.

The erroneous formula occurs near the middle of page 371 of the 'Report of the British Association' for 1872, in the instructions for clearing the diurnal means from the influence of the short-period tides; in the first of the two formulæ for that purpose, the factor, $\sin 12n/\sin \frac{1}{2}n$, should obviously be replaced by $\sin 24n/\sin n$.

I shall now therefore go over the process of clearing, shall evaluate the effect of non-clearance, and shall indicate what I conceive to be improvements in the method of the Tidal Report.

On any day, the height of water above the datum line is measured at $0^h, 1^h, 2^h \ldots . 24^h$; then the mean height of water for that day may be taken as $\frac{1}{24}$th of the sum of the 25 heights less the mean of the heights at 0^h and 24^h. In the Report the instruction is to take $\frac{1}{24}$th of the sum of the heights at $0^h, 1^h \ldots . 23^h$. At the time that I wrote this paper I conceived this to be less accurate than the method here suggested. But after conversation with Sir William Thomson, I perceive that the rule of the Report is just a shade more accurate than that here suggested. If, however, it were practically more convenient to find the heights of the tides of short periods at each midnight (see below) instead of at 11.30, then the rule here given would be practically preferable. As the computations in this paper have been made from the rule as here suggested, I leave the analysis in the form in which it stood originally.

We wish to find how much this diurnal mean is influenced by a short-period tide, for which the expression is $R \cos (nt-\epsilon)$.

Now let t_0 be the time at 0^h of the day in question, measured from the epoch when $t=0$.

The uncleared daily mean has obviously involved

$$\tfrac{1}{24} R \Big\{ \tfrac{1}{2} \cos [nt_0 - \epsilon] + \cos [n(t_0+1)-\epsilon] + \ldots .$$

$$+ \cos\left[n(t_0 + 23) - \epsilon\right] + \tfrac{1}{2}\cos\left[n(t_0 + 24) - \epsilon\right]\Big\}$$

$$= \tfrac{1}{24} R\left\{\frac{\sin \frac{25}{2} n}{\sin \frac{1}{2} n}\cos\left[n(t_0 + 12) - \epsilon\right]\right.$$

$$\left. - \tfrac{1}{2}\cos\left[nt_0 - \epsilon\right] - \tfrac{1}{2}\cos\left[n(t_0 + 24) - \epsilon\right]\right\}$$

$$= \tfrac{1}{24} R\frac{\sin 12 n}{\tan \frac{1}{2} n}\cos\left[n(t_0 + 12) - \epsilon\right]$$

[The formula derived from the rule in the Report has $\sin \frac{1}{2}n$ in place of $\tan \frac{1}{2}n$, and $t_0 + 11\frac{1}{2}$ in place of $t_0 + 12$.]

If 0^h is noon, then $t_0 + 12$ is midnight of the day in question. The speed n is generally given in degrees per m.s. hour; but if we write ν for $24n$, and τ for $\frac{1}{24}(t_0 + 12)$, so that ν is the speed in degrees per m.s. day, and τ the time in days from the epoch up to the first midnight in the year, then $n(t_0 + 12) = \nu\tau$. The corresponding term for successive days is to be found by writing $\tau + 1, \tau + 2, \ldots$ for τ. If, then, we wish to clear the daily mean from the influence arising from the tide of speed n, it is obvious that we must subtract $\frac{1}{24} R \sin 12n \cot \frac{1}{2}n \cos\left[\nu(\tau + i) - \epsilon\right]$ from the diurnal mean corresponding to the $(i + 1)$th day. The same should be done for each short-period tide, which experience shows may exercise a sensible effect on the result. But in the present instance we have to trace the results of non-clearance.

The next step is to find the mean height of water for the whole year. There are altogether $365 \times 24 + 1$ heights given, being those at each hour from 0^h of day 1 to 24^h of day 365. The proper mean is $\frac{1}{365 \times 24}$ of the sum of the $365 \times 24 + 1$ heights less the mean of the heights at 0^h of day 1 and 24^h of day 365. From the manner in which the diurnal means were formed this is clearly $\frac{1}{365}$ of the sum of the diurnal means.

Now when there is no clearance, it was shown above that the diurnal mean for the $(i + 1)$th day contains the undue term:—

$$\tfrac{1}{24} R\frac{\sin 12 n}{\tan \frac{1}{2} n}\cos\left[\nu(\tau + i) - \epsilon\right]$$

And therefore the annual mean contains the undue term:—

$$\frac{1}{365 \times 24} R\frac{\sin 12 n}{\tan \frac{1}{2} n}\cdot\frac{\sin 182\nu}{\sin \frac{1}{2}\nu}\cos\left[\nu(\tau + 182) - \epsilon\right]$$

Since $12n$ is identical with $\frac{1}{2}\nu$, $\sin 12n$ divides out with $\sin \frac{1}{2}\nu$, and the result is exactly what we should have found if the mean had been obtained by considering the series of hourly values throughout the year, with attention to the rule of only taking a half of the first and last terms. This is obviously correct.

It will be shown below how much this improper term in the expression for mean water will affect the result.

The next step is to find how much the diurnal means depart from mean water; these differences are then to be the subject of harmonic analysis for the purpose of extracting the long-period tides.

Each diurnal mean is subtracted from the annual mean, leaving residuals δh. For the $(i + 1)^{\text{th}}$ midnight the undue term in δh is clearly

$$\tfrac{1}{24} R \frac{\sin 12n}{\tan \frac{1}{2} n} \left\{ \tfrac{1}{366} \frac{\sin 182\nu}{\sin \frac{1}{2}\nu} \cos\left[\nu(\tau + 182) - \epsilon\right] - \cos\left[\nu(\tau + i) - \epsilon\right] \right\}.$$

Then unless $\frac{1}{2}\nu$ differs by an exceedingly small amount from 180° or 360°, the first of these terms within { } is small compared with the second, except for those terms (if any) in which $\nu(\tau + i) - \epsilon$ is very nearly equal to 90° or 270°, whilst $\nu(\tau + 182) - \epsilon$ is nearly equal to zero or 180°.

Even in the case of the K tides, in which the diurnal speeds are respectively 360° 59′ 8″, and 721° 58′ 16″, the coefficient of the first term is small, being respectively ·00339 and ·00340 for the two K tides. Hence the improper term in the residual δh_i is to a close degree of approximation.

$$- \tfrac{1}{24} R \frac{\sin 12n}{\tan \frac{1}{2} n} \cos[\nu(\tau + i) - \epsilon]$$

The δh's have now to be submitted to harmonic analysis for extracting the long-period tides, but as the values of δh are given discontinuously for each midnight, the continuous integrals, which arise in such analysis, are replaced by finite integrals.

It is now assumed that

$$\delta h = \Sigma[A \cos \lambda\tau + B \sin \lambda\tau]$$

Where Σ denotes summation for all the values of λ, which the theoretical development of the tide-generating potential, or other considerations indicate as likely to give sensible results. In the tidal report there are five values of λ, namely 2σ, $\sigma - \varpi$, $2(\sigma - \eta)$, 2η, η. I here suppose λ to be expressed in degrees per m.s. day.

Now let λ_1 be the speed of the special long-period tide for which we are searching; and A_1, B_1 the amplitudes of the components which it is required to evaluate. Then

$$\begin{aligned}\delta h \cos \lambda_1\tau = \tfrac{1}{2} A_1(1 + \cos 2\lambda_1\tau) + \tfrac{1}{2} B_1 \sin 2\lambda_1\tau \\ + \Sigma[A \cos \lambda\tau \cos \lambda_1\tau + B \sin \lambda\tau \cos \lambda_1\tau]\end{aligned}$$

$$\begin{aligned}\delta h \sin \lambda_1\tau = \tfrac{1}{2} B_1(1 - \cos 2\lambda_1\tau) + \tfrac{1}{2} A_1 \sin 2\lambda_1\tau \\ + \Sigma[A \cos \lambda\tau \sin \lambda_1\tau + B \sin \lambda\tau \sin \lambda_1\tau]\end{aligned}$$

Where Σ denotes summation for all values of λ except λ_1. By means of the known numerical value of λ_1, $\cos \lambda_1(\tau + i)$ and $\sin \lambda_1(\tau + i)$ may be computed for every midnight in the year, and the results multiplied by the corresponding δh_i, whether cleared or uncleared of undue influence.

Now if we form $\sum\limits_{i=0}^{i=364} \delta h_i \cos[\lambda_1(\tau + i)]$, it is obvious that A_1 will be multiplied by a coefficient differing but little from 183, and that the coefficient of B_1, and all the other coefficients of the A's and B's, will be small. Similarly, the coefficient of B_1 in $\sum\limits_{i=0}^{i=364} \delta h_i \sin[\lambda_1(\tau + i)]$ will be nearly 183, and all the other coefficients small. Proceeding in the same way with each long-period tide we shall obtain twice as many equations as there are long-period tides, in each of which there is one unknown A or B with a coefficient nearly equal to 183. These equations may be solved by successive approximation, and the two components of each tide evaluated.

We must now trace the undue term through this process.

The undue term in the equation in which A_1 has the large coefficient is

$$-\sum_{i=0}^{i=364} \tfrac{1}{24} R \frac{\sin 12n}{\tan \frac{1}{2}n} \cos [\nu(\tau + i) - \epsilon] \cos \lambda_1(\tau + i)$$

Omitting the factor $-\frac{1}{48} R \sin 12n \cot \frac{1}{2}n$, and dropping the suffix 1 to λ, this becomes

$$\sum_{i=0}^{i=364}\left[\cos [(\nu + \lambda)(\tau + i) - \epsilon] + \cos [(\nu - \lambda)(\tau + i) - \epsilon]\right]$$

$$= \frac{\sin 182\frac{1}{2}(\nu + \lambda)}{\sin \frac{1}{2}(\nu + \lambda)} \cos [(\nu + \lambda)(\tau + 182) - \epsilon]$$

$$+ \frac{\sin 182\frac{1}{2}(\nu - \lambda)}{\sin \frac{1}{2}(\nu - \lambda)} \cos [(\nu - \lambda)(\tau + 182) - \epsilon]$$

Supposing the observations to begin at noon of January 1, $\tau + 182$ is midnight of civil time of July 1–2, which time we may call $\mathbf{t}$.

This expression, multiplied by $-\frac{1}{48} R \sin 12n \cot \frac{1}{2}n$, gives the undue term due to the short tide of speed n. The maximum possible effect then occurs when

$$(\nu + \lambda)\,\mathbf{t} - \epsilon = 0°, \text{ or a multiple of } 360°$$
$$(\nu - \lambda)\,\mathbf{t} - \epsilon = 0°, \text{ or a multiple of } 180°$$

and then the effect is

$$-\tfrac{1}{48} R \frac{\sin 12n}{\tan \frac{1}{2}n}\left\{\frac{\sin 182\frac{1}{2}(\nu + \lambda)}{\sin \frac{1}{2}(\nu + \lambda)} \pm \frac{\sin 182\frac{1}{2}(\nu - \lambda)}{\sin \frac{1}{2}(\nu - \lambda)}\right\}$$

the alternative sign being so chosen that the two terms within { } add together.

Now in the special equation which we are considering, the coefficient of A_1 is nearly 183, and all the other coefficients of A's and B's are small. Hence an approximate value for the part of A_1 which arises from the influence of the short-tide n on the long-tide λ, when at its maximum is, without regard to sign,

$$\frac{1}{183 \times 48} R \frac{\sin 12n}{\tan \frac{1}{2}n}\left\{\frac{\sin 182\frac{1}{2}(\nu + \lambda)}{\sin \frac{1}{2}(\nu + \lambda)} \pm \frac{\sin 182\frac{1}{2}(\nu - \lambda)}{\sin \frac{1}{2}(\nu - \lambda)}\right\}$$

The same result arises from the discussion of the equation in which B_1 has the large coefficient.

There is one case in which this formula fails, and as that case actually arises in the harmonic analysis of the long-period tides, it must be considered in detail. If either $\frac{1}{2}(\nu + \lambda)$ or $\frac{1}{2}(\nu - \lambda)$ is an exact multiple of 180° the formula becomes indeterminate.

Suppose, for example, that $\nu + \lambda = 2r\pi$, then

$$\cos[(\nu + \lambda)\ (\tau + i) - \epsilon] = \cos[(\nu + \lambda)\,\tau - \epsilon] \text{ and}$$

$$\sum_{0}^{364}\left[\cos[(\nu + \lambda)(\tau + i) - \epsilon] + \cos[(\nu - \lambda)(\tau + i) - \epsilon]\right]$$

$$= 365 \cos[(\nu + \lambda)\,\tau - \epsilon] + \frac{\sin 182\frac{1}{2}\,(\nu - \lambda)}{\sin \frac{1}{2}\,(\nu - \lambda)} \cos[(\nu - \lambda)(\tau + 182) - \epsilon]$$

We thus see that when $\frac{1}{2}(\nu \pm \lambda)$ is a multiple of 180°, we must interpret the indeterminate expression $\sin 182\frac{1}{2}(\nu \pm \lambda)/\sin \frac{1}{2}(\nu \pm \lambda)$ as being equal

to 365. By aid of this rule the formula for undue influence becomes universally applicable.

The manner in which this inconvenient result is brought about is curious.

The finite integrals Σ, which arise in the harmonic analysis, are of course the representatives of the integrals which arise in the analysis of continuous functions. In general, the distinction between Σ and $\int$ would be quite insensible.

$$\text{Now} \int_{-\frac{1}{2}}^{364\frac{1}{2}} \cos\lambda\tau\cos(\lambda\tau - \epsilon)d\tau = \frac{1}{2(\nu+\lambda)}\left\{\begin{array}{l}\sin[364\tfrac{1}{2}(\nu+\lambda)-\epsilon] \\ +\sin[\tfrac{1}{2}(\nu+\lambda)+\epsilon]\end{array}\right\}$$
$$+\frac{1}{2(\nu-\lambda)}\left\{\begin{array}{l}\sin[364\tfrac{1}{2}(\nu-\lambda)-\epsilon] \\ +\sin[\tfrac{1}{2}(\nu-\lambda)+\epsilon]\end{array}\right\}$$

If $\frac{1}{2}(\nu \pm \lambda)$ be 360° the corresponding term within { } vanishes. It would seem therefore at first sight, that the result of the finite integral, in which the term becomes large instead of vanishing, must be erroneous.

The discrepancy enters in the assumption practically made in the treatment through diurnal means, that because the long-period tide varies slowly it is sufficiently accurate to estimate its height only once in the twenty-four hours.[1]

The expression $\sum_0^{364} \delta h_i \cos\lambda(\tau + i)$ is of course intended to be, and in general is, a sufficiently close approximation to $\sum_{j=0}^{j=365\times 24} \delta h'_j \cos \frac{1}{24}\lambda(t+j)$, where j is the number of m.s. hours since 0^h of day 1, and $\delta h'_j$ is the departure from mean water at the jth hour, and where we take a half of the first and last terms. The term due to the tide n in $\delta h'_j$ is of course $R\cos[n(t+j)-\epsilon]$. Then if we effect the summations involved in this expression, we shall find that one of the two terms vanishes when $\frac{1}{2}(\lambda \pm \nu) = 360°$, just as it does in the continuous integral.

It follows therefore that the method by diurnal means leads to a considerably different result from that by hourly values, or by continuous integration. This does not constitute a reason for discarding the method of diurnal means in these special cases, but it is necessary to pay careful attention to the terms introduced in that process.

The five long-period tides for which the harmonic analysis has been practically carried out are those of speeds 2σ, $\sigma - \varpi$, $2\sigma - 2\eta$, 2η, η. We have to consider what values of n added to or subtracted from these speeds will give resulting speeds of $\gamma - \eta$ or $2\gamma - 2\eta$, that is to say of 15° or 30° per m.s. hour.

The accompanying schedule gives the values of (n) which give these results.

Amongst the resulting speeds there are only a few which correspond with actually existing sensible short-period tides. These are marked in

[1] The point of view from which I here regard the problem of clearing the daily means is, as I learn from Sir William Thomson, somewhat different from that supposed to be adopted in the Tidal Report. It is there supposed that the results of the previous harmonic analysis for the tides of short period are utilised to subtract the tide of short period from every hourly value of the height of water, but instead of making twenty-four subtractions for each day, a twenty-fourth part of the sum of the quantities to be subtracted is taken from the diurnal mean. From this point of view a result practically identical with that in the text may be obtained.

the schedule with an asterisk, and with the initial letter by which the tide is denoted in the Tidal Reports.

TABLE I.

Speed or $\frac{1}{24}\lambda$	Theoretical values of n or $\frac{1}{24}\nu$.	
Fortnightly (2σ)	$\gamma - \eta + 2\sigma$ $\gamma - \eta - 2\sigma$	$2\gamma - 2\eta + 2\sigma$ $2\gamma - 2\eta - 2\sigma$
Elliptic Monthly $(\sigma - \varpi)$	$\gamma - \eta + \sigma - \varpi$ $\gamma - \eta - \sigma + \varpi$	$2\gamma - 2\eta + \sigma - \varpi$ $*2\gamma - 2\eta - \sigma + \varpi$ (λ)
Synodic Fortnightly $2(\sigma - \eta)$	$\gamma + 2\sigma - 3\eta$ $\gamma - 2\sigma + \eta$	$2\gamma + 2\sigma - 4\eta$ $*2\gamma - 2\sigma$ (M)
Semiannual (2η)	$\gamma + \eta$ $\gamma - 3\eta$	$*2\gamma$ (K) $2\gamma - 4\eta$
Annual (η)	$*\gamma$ (K) $*\gamma - 2\eta$ (P)	$*2\gamma - \eta$ (R) $*2\gamma - 3\eta$ (T)

The fortnightly tide is free from the cumulative influence arising from the method of diurnal means. But as we shall see below, the elliptic monthly tide is sensibly altered by this cause.

The synodic fortnightly is affected in this way by the principal lunar semidiurnal tide, and the semiannual by a much less important semidiurnal tide. The annual tide may apparently be much influenced, since all four speeds actually exist as sensible tides, but the numerical computation made below seems to show that the resulting influence is not large.

In the Report of 1872 it is stated that the only tides which are found practically to have a sensible effect, so that the diurnal means have to be purified from their effects, are the semidiurnal M or $2\gamma - 2\sigma$, the semidiurnal N or $2\gamma - 3\sigma + \varpi$, and the diurnal O or $\gamma - 2\sigma$. I have therefore computed the following tables, giving superior limits to the undue influence on the height of mean water for the year, and on the height of the five long-period tides. In the case of the synodic fortnightly tide, the cumulative influence arises which has just been discussed.

The numerical values of the speeds are taken from the Tidal Reports, and substituted in the formulæ given above.

First, for the effect on mean watermark, the superior limit is $R\frac{1}{365 \times 24}\sin 182\,\nu \cot \frac{1}{2}n$.

The following are the computed values of this coefficient of R:—

TABLE II.

From tide M	·000392
From tide N	·000188
From tide O	·000834

The following is a numerical example illustrative of the practical result. At Liverpool in 1857–8, the values of R for the M, N, O tides were respectively 9·6745, 1·8608, 0·4410 in British feet; and for 1869–70 they were 10·1443, 1·897, 0·3314.

Therefore supposing the phases in those years to have been such as to make the result a maximum, the following would have been the errors in the height of mean water:—

TABLE III.

	1857–8 Feet	1869–70 Feet
From tide M	0·00379	0·00398
From tide N	0·00035	0·00036
From tide O	0 00037	0·00027
Total	0 00451	0·00461

We thus see that the effect of working with unpurified diurnal means would be small, although sensible.

I next go on to compute the value of the coefficient

$$\frac{1}{183 \times 48} \frac{\sin 12 n}{\tan \frac{1}{2} n} \left\{ \frac{\sin 182\frac{1}{2} (\nu + \lambda)}{\sin \frac{1}{2} (\nu + \lambda)} \pm \frac{\sin 182\frac{1}{2} (\nu - \lambda)}{\sin \frac{1}{2} (\nu - \lambda)} \right\}$$

for the combinations of the M, N, O tides with the five long tides. In computing the factor arising from the influence of the M tide on the lunar synodic fortnightly, we must remember that $\sin 182\frac{1}{2} (\nu + \lambda) / \sin \frac{1}{2} (\nu + \lambda)$, which becomes $0/0$, is equal to 365.

TABLE IV.

	2σ	$\sigma - \varpi$	$2\sigma - 2\eta$	2η	η
(M) $2\gamma - 2\sigma$	·000235	·000969	·034175	·000683	·000679
(N) $2\gamma - 3\sigma + \varpi$	·001278	·000736	·001120	·000094	·000094
(O) $\gamma - 2\sigma$	·000508	·001969	·000525	·001440	·001446

At the intersection of any column and row is found the factor corresponding to the maximum undue influence of the short tide on the long. For example, the effect of the M tide $(2\gamma - 2\sigma)$ on the synodic fortnightly tide $(2\sigma - 2\eta)$ may be as great as ·034175 of the semi-range R of the M tide.

Applying these factors to the cases of Liverpool, as quoted above, in 1857–8 and 1869–70; that is to say, multiplying the M row by 9·6745 and 10·1443, the N row by 1·8608 and 1·8917, and the O row by ·4410 and ·3314, we get the following superior limits, expressed in feet, to the undue influence on the semi-range R of the several long-period tides:—

TABLE V.

	2σ	$\sigma - \varpi$	$2\sigma - 2\eta$	2η	η
	Feet	Feet	Feet	Feet	Feet
1857–8	·00488	·01160	·33093	·00742	·00738
1869–70	·00497	·01187	·34897	·00757	·00753

Having regard to the values of the long tides, as given in the results of the harmonic analysis of the tides in the Reports and the Indian Tide

Tables, we see that in the case of the synodic fortnightly the results of undue influence are very serious, and improper purification of daily means will have rendered the results utterly worthless. The value of the monthly elliptic tide may be very perceptibly affected by the M, N, O tides, but the values of the fortnightly, semiannual, and annual tides will not have been very considerably altered. M, N, O are, however, only three of the tides exercising influence, and it will be shown below that the monthly elliptic tide may be further affected.

The other tides, whose effects it is well to consider, are those in which $\frac{1}{2}(\nu \pm \lambda)$ is a multiple of 180°, for, as shown above, in these cases the method of procedure by diurnal means leads to a cumulative influence.

Referring back to Table I. we see that the following are the cases of this peculiar influence: (1) the semidiurnal λ tide on the elliptic monthly; (2) the semidiurnal M tide on the synodic fortnightly (already considered); (3) the semidiurnal K tide on the semiannual; (4) the diurnal K and P tides, and the semidiurnal R and T tides on the annual tide.

A rough approximation will suffice in these cases, and this may be made by only paying attention to that one of the two terms representing undue influence, in which there occurs the indeterminate expression $0/0$. It has already been shown that $0/0$ is here equal to 365. Then remembering that the 183 in the denominator of the expression for undue influence is itself approximate, and may be treated as a half of 365, we see that the required expression is simply

$$\tfrac{1}{24} R \sin 12n \cot \tfrac{1}{2}n.$$

The numerical values of n, the speed in degrees per m.s. hour, for the λ, K, K, R, T tides will be found in the Report for 1876.

From these we may compute $\frac{1}{24} \sin 12n \cot \frac{1}{2}n$. Then, as a numerical example we may take the corresponding semi-ranges R for the λ, K, K, R, T tides for Liverpool in the years 1857–8 and 1869–70, and assuming that the phases in those years were such as to make the influence a maximum, we may compute the maximum influence. The results of these calculations are embodied in the following Table VI.

TABLE VI.

Influence of	$\frac{1}{24}\frac{\sin 12n}{\tan \frac{1}{2}n}$	Semi-ranges in feet of the short tides at Liverpool		Maximum undue influence at Liverpool in feet	
		1857–8	1869–70	1857–8	1869–70
the short tide λ on the elliptic monthly	·01803	·4091	·1913	·00738	·00335
the short tide K (semidiur.) on the semiannual	·00266	1·1850	·7882	·00316	·00210
the short tides K (diurn.), P, R, T on the annual	(K) ·00276 (P) ·00277 (R) ·00136 (T) ·00136	·3930 ·1250 ·1006 ·3490	·3404 ·0935 — —	·00204	—

From these results we see that the effect of non-clearance of daily means may be quite sensible, although not important. The elliptic monthly tide suffers most, as it did in the results given in Table V., and it seems to follow, from the nature of the mistake which has been made in the reductions, that the values of the elliptic monthly tide assigned in the various reports may be quite sensibly in error.

It appears from Mr. Roberts' letter in answer to Professor Adams, that the purification of diurnal means has been correctly carried out as regards the diurnal tides, but incorrectly as regards the semidiurnal. In fact, if n be the speed per hour of a semidiurnal tide, $\sin 12n/\sin\frac{1}{2}n$ has the opposite sign from $\sin 6n/\sin\frac{1}{4}n$ (which is the factor which has actually been used), and therefore the corrections arising from the semi-diurnal tides have been applied with the wrong signs.

We may conclude from the preceding discussion that the values deduced for the fortnightly, semiannual, and annual tides are not seriously vitiated; those for the monthly elliptic tide may be sensibly affected; and that for the synodic fortnightly is utterly worthless.

Although I have not seen the actual computations for reducing the long tides, yet it appears certain that the process of clearing the diurnal means must be very laborious. The preceding analysis shows that it is perfectly practicable to work with uncleared daily means up to the last stage, in which the final equations for the A's and B's are formed, and the proper corrections may be then applied. The numerical coefficients

$$\frac{1}{24}\frac{\sin 12n}{\tan\frac{1}{2}n}\frac{\sin 182\frac{1}{2}(\nu+\lambda)}{\sin\frac{1}{2}(\nu+\lambda)} \text{ and } \frac{1}{24}\frac{\sin 12n}{\tan\frac{1}{2}n}\frac{\sin 182\frac{1}{2}(\nu-\lambda)}{\sin\frac{1}{2}(\nu-\lambda)},$$

may be computed once for all, for the influence of each short tide on each long tide.

Then $\nu(\tau+182)-\epsilon$ is the phase of the short tide at midnight, July 1–2, and if time is measured from noon or 0^h of January 1, τ is $\frac{1}{2}$ and $\lambda \times 182\frac{1}{2}$ may be computed once for all for each long tide.

Thus the greater part of the materials for the corrections may be kept ready to hand, and the corrections from even four of five tides may be applied very quickly.

The practical recommendation for future operations which I have to make is, that the clearance should not be effected for each day's mean, but only in the final equations.

List of Works on the Geology and Palæontology of Oxfordshire, of Berkshire, and of Buckinghamshire. By WILLIAM WHITAKER *B.A., F.G.S.*

[A communication ordered by the General Committee to be printed *in extenso* among the Reports.]

1. PREFATORY NOTE.

This is a continuation of the County or District Lists, of which a Catalogue was given at the head of the Welsh List in the Report for 1880 (p. 397). The only additions since made (except the reprints of

Cambridgeshire and Nottinghamshire therein noticed) being as follows:—

CHESHIRE. Reprinted, with additions, in the *Geological Survey Memoir* on sheet 80, S.W., pp. 40–52.

CUMBERLAND. *Trans. Cumberland Assoc.* (now printing).

NORFOLK. By W. WHITAKER and H. B. WOODWARD, pp. 171-204 of 'The Geology of the Country around Norwich,' 1882 [wrongly dated 1881]. *Geological Survey Memoir.*

In the List now brought forward the same plan has been pursued as in that for Wales.

The Oxfordshire List has been taken first of the three counties, as probably of the most interest (in view of the proposed British Association Meeting of 1883).[1] Works already entered under that county are not again entered under the others, but referred to by their numbers, except in the case of some Geological Survey maps, of which it is convenient to note the parts that refer to each county. In like way works entered under Berks are referred to by number under Bucks.

Perhaps some of the general works noticed in the London Basin List (*Geological Survey Memoirs*, vol. iv.) may refer to these counties, besides those now included (see Nos. 13, 46, 55, 57, and 193 of that List).

2. INDEX OF AUTHORS, WITH THE NUMBERS PREFIXED TO THE TITLES OF THEIR WORKS.

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[1] This list was of course written before Oxford had been given up as the place of meeting; indeed, it was written only on account of the arrangement for meeting at Oxford.

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3. OXFORDSHIRE.

A. Geological Survey Publications.

Maps.

(1) Sheet 7 (very small part at W. edge). By W. Whitaker, 1861. Drift edition. By J. H. Blake, 1872.

(2) Sheet 13 (part. Bamford, Henley, Oxford, Thame, Watlington). By E. Hull, H. Bauerman, and W. Whitaker, 1860.

(3) Sheet 34 (very small part at N.E. corner). By E. HULL, 1857.

(4) Sheet 44 (small part at S.E. corner. Burford). ? By H. H. HOWELL and E. HULL, 1856.

(5) Sheet 45, S.W. (Witney, Woodstock). By E. HULL, 1859.

(6) Sheet 45, N.W. (greater part. Chipping Norton, Deddington). By H. BAUERMAN and T. R. POLWHELE, 1859.

(7) Sheet 45, S.E. (W. part. Bicester). By E. HULL, W. WHITAKER, T. R. POLWHELE, and A. H. GREEN, 1863.

(8) Sheet 45, N.E. (S.W. corner). By T. R. POLWHELE and A. H. GREEN, 1863.

(9) Sheet 53, S.W. (small part on S.). By H. H. HOWELL, 1855.

(10) Sheet 53, S.E. (very small part in S.W. corner), 1859.

Horizontal Sections.

(11) Sheet 71. From Nettlebed Hill, Oxfordshire, on the south to the Burton Bassett Hills, Worcestershire. By E. HULL and W. WHITAKER, 1867.

(12) Sheet 72. No. 2. From Lambourne Downs, Berkshire, on the south. . . . . . . By E. HULL, 1867.

(13) Sheet 81. From White Hill near Kingsclere in Hampshire to Pinsley Wood near Handborough, in Oxfordshire. By H. W. BRISTOW and E. HULL, 1870.

(14) Sheet 82 (part). From Handborough in Oxfordshire to Milverton near Warwick. By E. HULL and J. W. JUDD, 1870.

Memoirs.

(15) The Geology of Parts of Middlesex, Hertfordshire, Buckinghamshire, Berkshire, and Surrey (sheet 7). By W. WHITAKER, 1864. (Refers to a very small part of Oxfordshire).

(16) The Geology of Parts of Oxfordshire and Berkshire (sheet 13). By E. HULL and W. WHITAKER, 1861.

(17) The Geology of Parts of Wiltshire and Gloucestershire (sheet 34). [Refers to a very small part of Oxfordshire.] By E. HULL, 1858.

(18) The Geology of the Country around Cheltenham (sheet 44). By E. HULL, 1857. [Refers to a very small part of Oxfordshire].

(19) The Geology of the Country around Woodstock (45, S.W.). By E. HULL, 1859.

(20) The Geology of the Country around Banbury, Woodstock, Bicester, and Buckingham (sheet 45). By A. H. GREEN [parts from E. HULL and parts by R. ETHERIDGE and W. WHITAKER], 1864.

(21) The Geology of the London Basin. Part I. The Chalk and the Eocene Beds of the Southern and Western Tracts (vol. iv.). By W WHITAKER, 1872.

(22) The Geology of Rutland, &c. . . . With an Introductory Essay on the Classification and Correlation of the Jurassic Rocks of the Midland District of England. [Refers to Oxfordshire.] By J. W. JUDD, 1875.

B. LIST OF BOOKS, PAPERS, ETC. CHRONOLOGICALLY ARRANGED.

No. 214 of the Berkshire List refers to Oxfordshire also.

1676.

(23) PLOTT, Dr. R. Natural History of Oxfordshire. Fol. *Oxford.* (? Other Editions in 1686 and 1705).

1693.

(24) LLOYD, E. Epistola in qua agit de lapidibus aliquot perpetuâ figurâ donatis, quos nuperis annis in Oxoniensi et Vicinis agris adinvenit. *Phil. Trans.* vol. xvii. No. 200, p. 746.

1754.

(25) BAKER, H. An Account of some uncommon fossil Bodies. *Phil. Trans.* vol. xlviii. p. 55.

1759.

(26) PLATT, J. An Account of the fossile Thigh-bone of a large Animal, dug up at Stonesfield, near Woodstock, in Oxfordshire. *Phil. Trans.* vol. l., pt. 2, p. 524.

1765.

(27) PLATT, J. An Attempt to Account for the Origin and the Formation of the Extraneous Fossil commonly called the Belemnite. *Phil. Trans.* vol. liv. p. 38.

1785.

(28) DOUGLAS, Rev. J. A Dissertation on the Antiquity of the Earth. (Note of a Fossil Jaw-bone from Thame.) 4to. *Lond.*

1809.

(29) YOUNG, A. View of the Agriculture of Oxfordshire. Drawn up for the Board of Agriculture (Map and Account of Soils). 8vo. *Lond.*

1813–1815.

(30) SOWERBY, J. The Mineral Conchology of Great Britain, vol. i. (pp. 51, 126, 191, 196). 8vo. *Lond.*

1815.

(31) KIDD, Dr. J. A Geological Essay on the Imperfect Evidence in Support of a Theory of the Earth (Description of Oxford Gravel in Chap. 17). 8vo. *Oxford.*

1816.

(32) ANON. Analysis of the Mineral Waters of Caversham, Berkshire [Caversham is in Oxfordshire]. *Ann. Phil.* vol. viii. p. 123.

1816–1818.

(33) SOWERBY, J. The Mineral Conchology of Great Britain, vol. ii. (pp. 5, 20, 27, 84, 111, 174). 8vo. *Lond.*

1819-1821.

(34) SOWERBY, J. The Mineral Conchology of Great Britain, vol. iii. (pp. 3, 5, 39–43, 46, 87, 92, 153, 167). 8vo. *Lond.*

1820.

(35) SMITH, W. Geological Map of Oxfordshire.

1821.

(36) BUCKLAND, Rev. Prof. W. Description of the Quartz Rock of the Lickey Hill in Worcestershire, and of the Strata immediately surrounding it; with considerations on the evidences of a Recent Deluge afforded by the gravel beds of Warwickshire and Oxfordshire, and the valley of the Thames from Oxford downwards to London. *Trans. Geol. Soc.* vol. v. p. 506.

1822.

(37) CONYBEARE, Rev. W. D., and W. PHILLIPS. Outlines of the Geology of England and Wales. 8vo. *Lond.*

1822-1823.

(38) SOWERBY, J. The Mineral Conchology of Great Britain, vol. iv. (pp. 2, 111, 114). 8vo. *Lond.*

1823.

(39) BUCKLAND, Rev. Prof. W. Reliquiæ Diluvianæ; or Observations on the Organic Remains contained in Caves, Fissures, and Diluvial Gravel, and on other Geological Phenomena, attesting the action of an Universal Deluge. (*Oxon.* pp. 175, 249.) 4to. *Lond.* Ed. 2 in 18—.

1824.

(40) BUCKLAND, Rev. Prof. W. Notice on the Megalosaurus or great Fossil Lizard of Stonesfield. *Trans. Geol. Soc.* ser. 2, vol. i. p. 390.

(41) FITTON, Dr. W. H. Inquiries respecting the Geological Relations of the Beds between the Chalk and the Purbeck Limestone in the South-east of England. *Ann. Phil.* ser. 2, vol. viii. pp. 365, 458. (Reprinted in 4to. in 1833.)

1824-1825.

(42) SOWERBY, J. The Mineral Conchology of Great Britain, vol. v. (pp. 65, 133). 8vo. *Lond.*

1825.

(43) KINGDOM, J. Letter on Bones from Chipping Norton (Geol. Soc.). *Ann. Phil.* ser. 2, vol. x. p. 229.

(44) PRÉVOST, C. Observations sur les schistes calcaires oolitiques de Stonesfield, dans lesquels ont été trouvés plusieurs ossements fossiles de mammifères. (*Soc. Philomath. Paris.*) *Ann. Sci. Nat.* vol. iv. p. 389.

1826.

(45) ANON. Observations regarding the Position of the Fossil Megalosaurus and Didelphis or Opossum at Stonesfield. *Edin. Phil. Journ.* vol. xiv. p. 303.

(46) SEDGWICK, Rev. Prof. A. On the Classification of the Strata which appear on the Yorkshire Coast. (*Oxon.* p. 350.) *Ann. Phil.* ser. 2, vol. xi. p. 339.

1826–1829.

(47) SOWERBY, J. and J. D. The Mineral Conchology of Great Britain, vol. vi. (pp. 16, 18, 55, 156, 179, 213, 225–227). 8vo. *Lond.*

1827.

(48) BRODERIP, W. J. Observations on the Jaw of a Fossil Mammiferous Animal found in the Stonesfield Slate. *Zool. Journ.* vol. iii. p. 408.

(49) FITTON, Dr. W. H. On the Strata of Stonesfield. *Ibid.* p. 412.

1829.

(50) CONYBEARE, Rev. W. D. On the Hydrographical Basin of the Thames, &c. *Proc. Geol. Soc.* vol. i. p. 145.

(51) STOKES, C. Letter explanatory of 3 Drawings of Echini (one from Stonesfield). *Trans. Geol. Soc.* ser. 2, vol. ii. p. 406.

1836.

(52) BUCKLAND, Rev. Prof. W. Notice on the Fossil Beaks of four extinct Species of Fishes, referrible to the Genus Chimæra, that occur in the Oolitic and Cretaceous Formations of England. With a Note by Prof. AGASSIZ. *Phil. Mag.* ser. 3, vol. viii. p. 4. (Abstract in *Proc. Geol. Soc.* vol. ii. p. 204 [1835].)

(53) FITTON, Dr. W. H. Observations on some of the Strata between the Chalk and the Oxford Oolite, in the South-east of England. *Trans. Geol. Soc.* ser. 2. vol. iv. p. 103. [Abstract, under a different title, in *Proc. Geol. Soc.* vol. i. p. 26 (1827).]

1837.

(54) DAUBENY, Dr. C. Letter on a Saline Spring near Oxford. *Trans. Geol. Soc.* ser. 2, vol. v. p. 263.

(55) STRICKLAND, H. E. Notices of the Red Marl and Lias of Worcestershire . . . . and of fossil freshwater Shells at Shotover Hill. *Ibid.* p. 260.

1838.

(56) BLAINVILLE [H. D.], de. Doubts respecting the Class, Family, and Genus to which the Fossil Bones found at Stonesfield, and designated by the names of Didelphis Prevostii and D. Bucklandii, should be referred. (Translated from *Comptes Rendus*, Aug. 20, p. 402.) *Mag. Nat. Hist.*, ser. 2, vol. ii. p. 639.

(57) BUCKLAND, Rev. Prof. W. On the Discovery of a Fossil Wing of a Neuropterous Insect in the Stonesfield Slate. *Proc. Geol. Soc.* vol. ii. p. 688.

1839.

(58) Blainville [H. D.], de. New Doubts relating to the supposed Didelphis of Stonesfield. (Translated from *Comptes Rendus*, Oct. 1838, p. 727.) *Mag. Nat. Hist.* ser. 2, vol. iii. p. 49.

(59) Ogilby, W. Observations on the Structure and Relations of the presumed Marsupial Remains from the Stonesfield Oolite. *Proc. Geol. Soc.* vol. iii. p. 21.

(60) Valenciennes, A. Observations upon the Fossil Jaws from the Oolitic Beds at Stonesfield, named Didelphis Prevostii and D. Bucklandii. (Translated from *Comptes Rendus*, vol. vii. p. 572, 1838.) *Mag. Nat. Hist.* ser. 2, vol. iii. p. 1.

1840.

(61) Owen, R. Report on British Fossil Reptiles. (*Oxon.* pp. 79–82, &c.) *Rep. Brit. Assoc.* for 1839, p. 43.

1841.

(62) Owen, Prof. R. Observations on the Fossils representing the Thylacotherium Prevostii . . . . and on the Phascolotherium Bucklandi. *Trans. Geol. Soc.* ser. 2, vol. vi. p. 47.

(63) —— A description of a portion of the skeleton of the Cetiosaurus, a gigantic extinct Saurian Reptile occurring in the Oolitic formations of different portions of England. *Proc. Geol. Soc.* vol. iii. p. 457.

1842.

(64) Owen, Prof. R. Report on British Fossil Reptiles. Part 2. (*Oxon.* pp. 62, 81, 88, 100, 145, 168.) *Rep. Brit. Assoc.* for 1841, p. 60.

1843.

(65) Egerton, Sir P. De M. G. On some new species of Fossil Chimæroid Fishes, with remarks on their general affinities. *Proc. Geol. Soc.* vol. iv. p. 153.

(66) Owen, Prof. R. Report on the British Fossil Mammalia. (*Oxon.* pp. 57, 73.) *Rep. Brit. Assoc.* for 1842, p. 54.

1844.

(67) Daubeny, Dr. C. On the occurrence of Fluorine in Recent as well as in Fossil Bones. (Chem. Soc.) *Phil. Mag.* ser. 3, vol. xxv. p. 122.

(68) Smith, W. Memoirs of, by Prof. J. Phillips (Section at Steeple Ashton, 1805, p. 61). 8vo. *Lond.*

1844 or 1845.

(69) Brodie, Rev. P. B. and J. Buckman. On the Stonesfield Slate of the Cotteswold Hills. *Proc. Geol. Soc.* vol. iv. p. 437, and *Quart. Journ. Geol. Soc.* vol. i. p. 220.

1848.

(70) Bowerbank, J. S. Miscroscopical Observations on the Structure of the Bones of Pterodactylus giganteus and other Fossil Animals. *Quart. Journ. Geol. Soc.* vol. iv. p. 2.

(71) M'COY, F. On some new Mesozoic Radiata. (*Oxon.* p. 403.) *Ann. Nat. Hist.* ser. 2, vol. ii. p. 397.

1849.

(72) STRICKLAND, H. E. On the Geology of the Oxford and Rugby Railway. *Proc. Ashmolean Soc. Oxon.* vol. ii. no. 25, p. 192.

1850.

(73) BRONGNIART, A. Chronological Exposition of the Periods of Vegetation and the different Floras which have successively occupied the surface of the Earth. (Stonesfield, p. 200). (Translated from *Ann. Sci. Nat. Bot.* 3 sér. t. xi. p. 285 [1849].) *Ann. Nat. Hist.* ser. 2, vol. vi. p. 192.

(74) ORLEBAR, A. B. On a Pygaster from the Coral Rag, Bullingdon. *Proc. Ashmolean Soc. Oxon.* vol. ii. No. 26, p. 242.

1851.

(75) DAVIDSON, T. A Monograph of British Oolitic and Liassic Brachiopoda. No. 1. (*Oxon.* p. 10.) *Palæontograph. Soc.*

(76) MILNE-EDWARDS, Prof. H., and J. HAIME. A Monograph of the British Fossil Corals. Second Part. Corals from the Oolitic Formations. (*Oxon.* p. 118.) *Ibid.*

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(151) PHILLIPS, Prof. J. Geology of Oxford and the Valley of the Thames. 8vo. *Oxford.*

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(152) BEESLEY, T. A Sketch of the Geology of the Neighbourhood of Banbury. 8vo. *Banbury*, and in *Proc. Warwicksh. Nat. Archæol. Field Club* for 1872 p. 11 (1873).

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4. BERKSHIRE.

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(174) SMITH, W. Geological Map of Berkshire. *Lond.*

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(199) ——— On a Reconstructed Bed on the top of the Chalk and underlying the Woolwich and Reading Beds. *Quart. Journ. Geol. Soc.* vol. xvii. p. 527.

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(203) ——— Notes on Brachiopoda . . . . with . . . . Remarks on the Correlation of the Greensand Beds of Kent, Surrey, and Berks, and of the Farringdon Sponge-gravel. . . . *Geol. Mag.* vol. i. p. 249.

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(211) ADAMS, Rev. J. A Geological Sketch of the Valley of the Kennet. *Mag. Wilts. Archæol. Nat. Hist. Soc.* vol. xi. No. 33, p. 268.

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5. BUCKINGHAMSHIRE.

A. GEOLOGICAL SURVEY PUBLICATIONS.

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(222) Sheet 13. (Very small part at N.E. corner.) 1860.

(223) Sheet 45, S.E. (E. part). By E. HULL, H. BAUERMAN, W. WHITAKER, and T. R. POLWHELE, 1863.

(224) Sheet 45, N.E. (Part on E. Buckingham). By T. R. POLWHELE and A. H. GREEN, 1863.

(225) Sheet 46, S.W. (More than half. Aylesbury). By E. HULL, H. BAUERMAN, W. WHITAKER, and A. H. GREEN, 1865.

(226) Sheet 46, N.W. (More than half. Fenny Stratford, Newport

Pagnell, Stony Stratford, Winslow). By H. BAUERMAN, W. WHITAKER, A. H. GREEN, and J. R. DAKYNS, 1864.

(227) Sheet 52, S.W. (Part on S. Olney). By H. H. HOWELL, 1863.

Horizontal Sections.

Sheet 74. (No. 163 of Berkshire List).

Memoirs.

Nos. 15, 16, 20, 21 of Oxfordshire List. No. 165 of Berkshire List.

B. BOOKS, PAPERS, ETC., CHRONOLOGICALLY ARRANGED.

[Nos. 63, 83, 106, 132, and 144 of the Oxfordshire List, and Nos. 188, 190, and 195 of the Berkshire List refer to Buckinghamshire also.]

1723.

(228) HOLLOWAY, Rev. B. An Account of the Pits for Fuller's-Earth in Bedfordshire [really in Buckinghamshire]. *Phil. Trans.* vol. xxxiii. No. 379, p. 419. Reprinted in Conybeare and Phillips' 'Geology of England and Wales,' p. 138. 8vo. *Lond.* 1822.

1809.

(229) ANON. (A. B. R.) [Note on Flint in Bucks.] *Monthly Mag.* vol. xxvii. p. 249.

1813.

(230) PRIEST, Rev. St. J. General View of the Agriculture of Buckinghamshire. (Account of Soils.) Reprinted with Additions. 8vo. *Lond.*

1820.

(231) SMITH, W. Geological Map of Buckinghamshire.

1830.

(232) ANON. Fossil Remains from Foxcote. *Mag. Nat. Hist.* vol. iii. p. 159.

1833.

(233) MITCHELL, Dr. J. On the Strata of Quainton and Brill in Buckinghamshire. *Proc. Geol. Soc.* vol. ii. p. 6.

1835.

(234) BUCKLAND, Rev. Prof. W. Notice of a newly discovered gigantic Reptile [near Buckingham]. *Proc. Geol. Soc.* vol. ii. p. 190.

1842.

(235) BRODIE, Rev. P. B. Notice on the Discovery of Insects in the Wealden of the Vale of Aylesbury, Bucks . . . . *Proc. Geol. Soc.* vol. iii. p. 780.

1845.

(236) BRODIE, Rev. P. B. A History of the Fossil Insects in the Secondary Rocks of England, accompanied by a particular Account of the Strata in which they occur. 8vo. *Lond.*

1847.

(237) IBBETSON, Capt. L. L. B. Sections shown by the Cuttings on the London and Birmingham Railway. No. 8, 55 miles from London to 49½.—No. 9, 49 miles from London to Leighton Station.—No. 10, Cheddington to Northchurch. MS. Drawings in Geological Survey Office.

1850.

(238) STOWE, W. On a Cutting in the Railway near Buckingham. *Quart. Journ. Geol. Soc.* vol. vi. p. 134.

1851.

(239) SMYTH, Adm. W. H. Ædes Hartwellianæ; or Notices of the Manor and Mansion of Hartwell [with Note on the Geology]. 4to. *Privately Printed.*

1855.

(240) PRESTWICH, J. On the Origin of the Sand and Gravel Pipes in the Chalk of the London Tertiary District. *Quart. Journ. Geol. Soc.* vol. xi. p. 64.

(241) READ, C. S. Report on the Farming of Buckinghamshire [with Geological Map and Sections, and Account of Soils]. *Journ. R. Agric. Soc.* vol. xvi. p. 269.

(242) WRIGHT, Dr. T. No. 195 of Berks List (inserted again by mistake).

1856.

(243) OWEN, Prof. R. Description of a Fossil Cranium of the Musk-Buffalo, from the Lower-level Drift at Maidenhead. [Taplow.] *Quart. Journ. Geol. Soc.* vol. xii. p. 124.

(244) PRESTWICH, J. Note on the Gravel near Maidenhead, in which the skull of the Musk Buffalo was found. *Ibid.* p. 131.

1858.

(245) WRIGHT, Dr. T. A Monograph of the British Fossil Echinodermata from the Oolitic Formations. Part Second, containing the Diademadæ, &c. (Bucks, pp. 166–168). *Palæontograph. Soc.*

1859.

(246) WRIGHT, Dr. T. A Monograph on the British Fossil Echinodermata from the Oolitic Formations. Part Third, containing the Collyritidæ, &c. (Bucks, pp. 353, &c.) *Palæontograph. Soc.*

1861.

(247) MACALISTER, J. H. Notes on the Geology of the Country round Newport Pagnell. *Geologist*, vol. iv. pp. 214, 263.

(248) —— Fossils of North Bucks and the Adjacent Counties. *Ibid.* p. 481. See also vol. v. pp. 38, 66.

(249) WRIGHT, Dr. T. A Monograph on the British Fossil Echinodermata from the Oolitic Formations. Part Fourth, containing the Echinolampidæ, the Stratigraphical Distribution of the Echinodermata, &c. (Bucks, p. 453). *Palæontograph. Soc.*

1865.

(250) WHITAKER, W. On the Chalk of Buckinghamshire, and on the Totternhoe Stone. *Quart. Journ. Geol. Soc.* vol. xxi. p. 398.

(251) Part of the South-eastern Sheet of the 'Greenough Map' of the Geological Society.

1866.

(252) SAEMANN, —. (Notes on Section at Hartwell) in 'Monographie paléontologique et géologique de l'étage portlandien des Environs de Boulogne-sur-Mer,' by E. de Loriol and P. Pellat. *Mém. Soc. Phys. Hist. Nat. Genève.*

1867.

(253) GREEN, A. H. The Valley of the Ouse at Buckingham. *Geol. Mag.* vol. iv. p. 563.

(254) MORRIS, Prof. J. On the Ferruginous Sands of Buckinghamshire, with Remarks on the Distribution of the Equivalent Strata. *Ibid.* p. 456.

(255) WOOD, S. V. jun. On the Structure of the Postglacial Deposits of the South-East of England. *Quart. Journ. Geol. Soc.* vol. xxiii. p. 394.

1868.

(256) GREEN, A. H. The Ouse Valley. *Geol. Mag.* vol. v. p. 104.

(257) WOOD, S. V. jun. Reply to . . . . Mr. A. H. Green, on the Ouse Valley at Buckingham. *Ibid.* p. 42.

1870.

(258) PHILLIPS, Prof. J. A Monograph of British Belemnitidæ. Part V. [Oxford Clay and Kimeridge Clay.] (Bucks, Pl. 36). *Palæontograph. Soc.*

1871.

(259) ANON. Excursion to Aylesbury. *Proc. Geol. Assoc.* vol. ii. No. 1, p. 36.

? date.

(260) PENNANT. Journey from Chester. [Fuller's-earth Pits (Wavendon) noticed.]

NOTE.—The lists of books, papers, &c., are not carried beyond 1873; works of later date being noticed in the volumes of the *Geological Record.*

Notes on the oldest Records of the Sea-Route to China from Western Asia. By Colonel H. YULE, *C.B., R.E.*

[A communication ordered by the General Committee to be printed *in extenso* among the Reports.]

THE purpose of this paper is to review, as concisely as may be practicable, the geography of the most ancient sea-trade with China, and to set forth the persistence of the maritime tradition of the route to that country during the first nine or ten centuries of the Christian era. In

the bulk of its detail this paper has little pretension to originality. I have myself at various times given attention to the subject, and have elaborated parts of it; but I shall make use of any books or papers which appear to me to contribute sound views, as well as of my own. I do not know of any work that treats the whole subject precisely as I propose to do.

The chief original sources of information are the following:—

1. The anonymous Periplus of the Erythraean Sea, the date of which we shall assume, after Dr. Carl Müller, to be about A.D. 80–90.

2. Ptolemy's Geographical Tables, dating about A.D. 150, and his extracts from Marinus of Tyre. The latter derived, apparently, a main part of his information regarding the sea-voyage from a navigator or trader of the name of Alexander, whose date may be put conjecturally about A.D. 100.

3. The 'Topographia Christiana' of Cosmas, *c.* A.D. 545.

4. The Arab Geography of Ibn Khordâdbah, in the first half of the 9th century; the first part of the Arabic Notices of India and China, last translated by M. Reinaud, dating from A.D. 851; and supplemented to some extent by the work of Mas'ûdi (*c.* 930–940).

The earliest of these writers, the author of the Periplus, knows *Thin*, of which *Thinai* was the chief city, lying inland and far towards the north. The country lay behind *Chrysê* (i.e. Indo-China), and where the sea comes to an end, i.e. where navigation then terminated. This country of *Thin* is difficult of access; it stretches from this eastern extremity of the earth far towards the north and west, so as to approach the Caspian. It sends silk and silk-stuffs to the ports of Western India, through Bactria, as well as by another route debouching on the Ganges.[1] The country thus defined is evidently, as its names would lead us to expect, *China*.

Ptolemy's statements (including those of Marinus) represent the great nation of the East, occupying the extremity of the known and inhabited earth, under a double aspect and title, viz., as *Seres*, when reached by the long land-route through Central Asia, and as *Sinae*, when reached by the sea-voyages, of which we shall speak more particularly.

In the notices of Cosmas we find the conception of China in a more distinct and modern shape, and the name now quite indisputable; but still there has been no break in the tradition. He has a correct idea of the position of *Tzinista* (or *Chînistán*), the remotest of all the Indies, and the country of silk, as lying on the extreme eastern coast of Asia, 'compassed by the ocean running round it to the left (i.e. the north), just as the same ocean compasses Barbary (i.e. the Somàl Country in Eastern Africa) round to the right' (or south). Beyond it was neither habitation nor navigation. To reach it the navigator passed the Pepper Country (i.e. Malabar), *Siëlediba* or *Taprobanê* (i.e. Ceylon), the coast of the Conch or *sănkh*-shells (Tinnevelly) and *Kaber* (probably the Cauvery Delta). Further off was the Clove Country (i.e. the Islands of the Indian Archipelago), and then *Tzinista*.

[1] It would be beside the present purpose to discuss this curious notice of such a trade route. See the present writer's Introductory Essay to Captain Gill's *River of Golden Sand*, and the other testimonies to such a traffic cited there. I will quote these words: '. . The trade that brought these stuffs must have been of that obscure hand-to-hand kind, probably through Tibet, analogous in character to the trade which in prehistoric Europe brought amber, tin, or jade from vast distances.' (*op. cit.* p. [32].)

We next come to the Arab voyagers of the 8th and 9th centuries. The most material difference between them and the navigators of the first century is that the latter, though acquainted with the direct monsoon courses, and sometimes using these for the voyage from the Red Sea and its vicinity to Guzerat and Malabar, did not apparently yet venture on the direct voyage across the Bay of Bengal.

But the nature of the trade, and the pick-up cargoes which are indicated in the Periplus, probably made the coasting voyage more usual even on this side of Cape Comorin.

Let us follow the Greek or Persian navigator from the Persian Gulf, taking him up where he first comes into Indian waters. He passes the low flat coast into which *Sinthos* (the Sind or Indus) discharges by seven mouths, touching at a port called *Barbaricon*, represented by the Lâri Bandar of later days. He then passes the dangerous shallows of the Gulf of *Irinon* (the *Iriṇa* or Rinn of Cutch) and *Barakê* (or Dvârakâ), and coasting *Syrastrênê* (Sorath, or Peninsular Guzerat), enters that other gulf by which he passes the island *Baiônês* (or Peram, famous in recent times for its extraordinary mammalian fossils), and so to the mouth of the *Namadus* (Narmada or Nerbudda) and its great port of *Barygaza* (Bhrigukachchha, Bharakachcha, or Barôch). Then coasting *Lârikê* (continental Guzerat, the ancient Hindu *Lâṭa*, and touching, among other marts, at *Suppara* (Supâra near Bassein—properly *Wasai*—north of Bombay, and where Mr. J. Campbell has lately been making excavations with interesting archæological results); at *Kalliena*, mentioned by Cosmas as well as the Periplus writer (Kalyâni, the chief town and port of Tanna district near Bombay, and the point where the Great Indian Peninsular Railway bifurcates after crossing the Tanna Strait), at *Sêmylla* or *Timûla* (*Saimúr* or Chaimûr of the Arabs, i.e. Chenwul or Chaul,[1] a port famous down to the beginning of the seventeenth century, and still existing,[2] too much reduced apparently to have a place in the 'Imperial Gazetteer,' though it has two or three lines in 'Thornton's'), and so forth along the coast of *Dachanabades* (i.e. of *Dakshinâpatha*, the 'southern region,' the *Deccan*), and beyond that to *Dimyrikê* (or the Tamil country) i.e. Malabar, in which the chief ports were *Naura* (i.e. Honâwar), *Nitria* (Mangalore on the *Netravati R.*, the *Mangaruth* of Cosmas), *Tyndis* (*Tundi* near Beypore), *Muziris* (Muyiri Kodu or Cranganore) and *Nelkynda*. The absolute identification of the last is not easy, but it was probably *Kallada*, on a river of the same name entering the backwaters, the only navigable river south of the *Perriár* at Cranganore. This is probably the same place as *Kanetti*, famous in the legendary history of Malabar; and it is still a great *entrepôt* for Travancore pepper, which is sent hence to the ports on the coast for shipment. That *Nelkynda* cannot have been far from this is clear from the vicinity of the Πυῤῥὸν ὄρος or 'Red Hill' of the Periplus, which is mentioned in immediate succession to the mouth of the river of Nelkynda. There can be no question that this is the bar of red laterite which a short distance south of Quilon cuts short the backwater navigation, and is thence called

[1] In foreign names the ṣ (*ṣwad* of the Arabs constantly, as may be seen in Prof. Sprenger's *Post- und Reise- Routen des Orients*, represents *ch*, a sound absent from Arabic.

[2] Mr. Burgess thinks Semylla may be a place called *Chemula*, which is said to have existed on Trombay Island, adjoining Bombay. But of this there seems to be little or nothing known.

the Warkallé Barrier. It forms abrupt cliffs on the sea, without beach, and these cliffs are still known to seamen (as the navigation books show) as '*the Red Cliffs*.' This is the only thing like a sea-cliff from Cananore (or perhaps from Mount d'Ely) to Cape Comorin. A little further is *Komarei* or *Komaria* (Cape Comorin), and beyond that *Kolchoi* and the pearl-fishery (*Korkai* or *Kolkai*, an ancient site near the mouth of the Tâmraparṇi River). The Periplus writer, as well as Ptolemy, it must be noted, regard, not Cape Comorin but the next succeeding Cape, called by Ptolemy *Kory* (i.e. *Koṭi*, the 'bow-tip,' the point of the island Râmeshwaram) as the southernmost point of India.

Here *Taprobanê* or Ceylon is apparently left to seaward, and the navigator passes through Palk's Strait and touching at several ports, such as *Nigama Metropolis* (of Ptolemy) probably Negapatam, *Kamara* (*Chabêris* emporium of Ptolemy, probably Kaveripatan, formerly a port of importance near the mouth of the Cauvery), *Pôdukê* and *Sopatma*, which we cannot identify, he reaches *Masalia*, or *Maisôlia* (*Ptol.*) the coast between the Kistna and Godavery, still marked by the name Masulipatan, which the striving after meaning has converted and vulgarised into *Machlîpatan*, or 'Fish Town.'

From *Masalia* the navigator of the Periplus 'crosses the Gulf,' i.e. giving a wide berth to the Godavery sands, and leaving to port the bay of Coringa, he strikes across the sea, making the land again in *Desarêne* or Orissa, perhaps taking for his landmark Mount Mahendra, the highest mountain on the coast (N. Lat. 19°4′, height 4,923 feet). From this point ships bound for the Ganges would renew their coasting; those bound for *Chrysê*, or Indo-China, took a fresh departure, and struck across the Bay nearly on a parallel of latitude to *Sada* in *Argyrê* or Arakan. Here, then, is the point which Ptolemy calls, Ἀφετήριον τῶν εἰς τὴν Χρυσῆν ἐμπλεόντων—not, as Lassen makes it, a harbour from which voyages to Chrysê were made, but the point of departure from which vessels bound thither struck off from the coast of India.

A little above this point Ptolemy has a town called *Palura*, which we still find—*Palûr*—in latitude 19° 27½, some five or six miles above Ganjam. This place is mentioned both by Barros (1552) and Linschoten (1597), and the passages in the Periplus and in Ptolemy to which we have been referring are aptly illustrated by extracts showing the course of navigation 1,500 to 1,600 years later.

Thus Linschoten has the following sailing directions (which I give slightly condensed):—

'In the August monsoon, after leaving the Ceylon coast, the navigator will keep north to the Cape called *Ponta de Guadovarin* [Point Godavery] in 17°. . . . He will then continue to run along the coast, taking care not to pass the 19½° [it should be 19°] without sighting land, for here there is the mouth of a river called Puacota. . . . All this coast from Point Guadovarin is high and mountainous, and easily seen from afar. From the river of Puacota to another called *Paluor* or *Palura*, a distance of twelve leagues, you run along the coast with a course from S.W. to E. Above this last river is a high mountain called *Serra de Palura*, the highest mountain on the coast. This river is in 19½°,' &c. The Palura river in 19½° must be the river of Ganjam (19° 23′), and the river of Puacota must be that of Barwa (18° 54′), which is just thirteen leagues down the coast. The latter, lying under Mount Mahendra, seems to answer precisely to Ptolemy's *Aphetêrion*.

Turning again to Valentijn's great book on the Dutch East Indies (1727), under a notice of Bimlipatam, we find the following:—

'In the beginning of February there used to ply, as long as the trade lasted, for the first despatch to Pegu, a little ship with such goods as were in demand, and which were taken on board at Masulipatam. . . . From that place it used to run along the coast up to 18° N. latitude, and then crossed seawards' [in fact it took its *aphetêrion*, but somewhat further south than the ancients] 'so as to hit the land on the other side about 16°, and then, on an off-shore wind, sailed very easily to the Peguan river of Syriang'[1] [Syriam, below Rangoon].

The Periplus carries us to the mouth of the Ganges, where there was a mart so-called (*Gangê*), and to the beginning of the Continent of *Chrysê*, i.e. Indo-China, but gives no further detail. For this we go to Ptolemy. He gives us the coast of *Argyrê* ('Silver-land') and *Chrysê Chersonnêsus*, with *Chrysê Chôra* behind it, 'the Golden Peninsula' and 'the Golden Region' In *Argyrê* we have undoubtedly Arakan, but I have been able to trace no Indian suggestion of the name, or of the *mines* which are said in Ptolemy to have existed in it. The Golden Chersonnese is specifically the protuberant Delta of the Irawadi, Pegu, the *Suvarṇa Bhûmi* or Golden Land of ancient India, whilst the Golden Region behind is Burma, the oldest province of which above Ava is still formally styled in State documents *Sona-paranta*—'Golden Frontier.' Ptolemy's *Chalkitis* also, or 'Copper Region,' approximates curiously to the *Tampa dîpa* or 'Copper Island' of the Burmese State phraseology, a region which embraces Ava and the ancient capital Pagán.

Proceeding further, the navigator reaches the city of *Kôli* or *Kôlis*, leaving behind him the islands of *Bazakota*, 'Good Fortune' ('Ἀγαθοῦ δαίμονος) and the group of the *Barusae*. Here at *Kôli*, which I take to be a port of the Malay Peninsula, the course of the first-century Greek and of the ninth-century Arab come together; and before going further it is desirable to take up the route of the latter.

The Arabs discriminated a variety of 'seas' that were passed on the route to China. First, of course, the starting-points being Obollah at the head of the Persian Gulf, or Sîrâf on its northern shore, is that sea (*Bahr Fârs*). Then the Sea of *Lâr* (*Bahr Lârawî*)—i.e., of the Greek *Larikê* of which we have spoken. This sea washed the shores of *Saimûr*, *Subara*, *Tânâ*, *Sindân*, and *Kambâya*. The last is well known; of Saimûr and Subara we have already spoken, as well as of *Thâna* (or Tanna, as the Gazetteer spells it) near Bombay; it was visited by Marco Polo in the end of the thirteenth century. *Sindân* is famous as the port where the Parsi immigration first landed in India, and has become, by an odd corruption, in our sea-nomenclature 'St. John's.'

The Sea of Lâr was reckoned to terminate at certain numerous islands known as the *Dîbas*, of which *Serendîb* (Ceylon) was the last and greatest; a view of things set forth in that passage of Ammianus which speaks of the rumours of Julian's accession (A.D. 361) as reaching even to the *Divi* and the *Serendivi*. Here began the 'Sea of Horkand,' a name which we cannot hesitate to identify with the *Rhogandani* whom Ptolemy places in the south of Taprobane, a name which long survived in the form of *Rôhana* or *Rohuna*, occurring often in the Mahâwanso, as a province of which Mahâgâmo, the *Maagrammon* of Ptolemy, was the capital, and which the early Mahommedans applied in the form *al-Rahûn* to Adam's Peak.

[1] *Valentijn*, 'Choromandel,' vol. v. pp. 44, 45.

The Sea of Horkand extended to *al-Râmnî*, identified with Sumatra not only by its position, but by its products (such as Fansûrî camphor, elephants, brazil-wood, and cannibals), and by its great extent. The compass of 800 parasangs ascribed to it corresponds roughly with the estimates of Sumatra which we find in Marco Polo ('2,000 miles or more'), and in Barbosa (2,100 miles), and with the truth, which is about 2,300 miles. The navigators, crossing the Sea of Horkand with the western monsoon, made land at the Islands of *Lanja-*, *Lankha*, or *Lika-Bâlûs*, where the naked inhabitants came off in their canoes, bringing ambergris and coco-nuts for barter; a description which, with the position, identifies these islands with the *Nicobars*, *Necuveram* of Marco Polo, *Lâka-vâram* of Rashîd-uddîn, and, I can hardly hesitate to say, the *Barusae* Islands of Ptolemy.

Beyond these, and not in the track usually followed, were the two islands of the *Andâmân* Sea, inhabited by dangerous and naked negro cannibals. Still further out of the way in this direction, and difficult of access, was a region of mountains containing mines of silver. The landmark to reach these was a mountain called *al-Khushnâmi* ('The auspicious').

This 'Land of silver mines,' both position and this description identify with the *Argyrê* of Ptolemy. As no silver is known to exist in that region (Arakan) it seems probable that the Arab indications to that effect were adopted from the Ptolemaic charts. And this leads me to suggest also that the Jibal *Khush-nâmi* also was but a translation of the Ἀγαθοῦ δαίμονος νῆσος, or Isle of Good Fortune, in those maps, whilst I have thought also that the name *Andâmân* might have been adopted from a transcript of the same name in Greek as ''Αγ. δαιμον. N.'[1]

At *Kôli*, or *Kûlis*, I have said the Greek and Arab routes coincide. For I take this *Kôli* to be the *Kalah* of the Arabs, which was a month's sail from Kaulam (Quilon) in Malabar, was a place dependant on the Mahârâja of Zâbaj (i.e. Java, or the Great Islands), and near which were the mountains producing tin. *Ko-lo* is also mentioned in the Chinese History of the T'ang dynasty in terms which indicate its position somewhere in the region of Malacca.[2]

Kalah lay on the Sea of *Shalâhit* (which we call the Straits of Malacca), but was not very far from the entrance of the Sea of *Kadranj*, a sea which embraced the Gulf of Siam; therefore I presume that Kalah was pretty far down the Malay Peninsula. It may, however, have been *Kadah*, or Quedda, as we write it. For it was ten days' voyage from Kalah to *Tiyûmah* (written also *Batûmah*, *Koyûmah*, &c.—a variation dependent on loose pointing chiefly), a place where they found supplies of fresh water. And this I take it is *Tiyûman* (in charts corruptly *Timoan*) on the eastern side of the Malay Peninsula. The island '*Timon*' is a point of note in Linschoten's 'Course from Malacca to Macau in China' (1597). 'Thereon,' he says, 'are two places where you find good fresh water.'

[1] *Bazakota*, and the 'Isle of Good Fortune,' may be taken as the Great and the Little Andaman respectively. The Arab *Relation* mentions, in an unconnected notice, an island called *Malhân* between Serendîb and Kalah, i.e. between Ceylon and the Malay Peninsula, which was inhabited by black naked cannibals. This may be another indication of the Andaman group, and the name may have been taken from Ptolemy's *Maniolae*, which in his map occupy the position in question.

[2] See *Bretschneider* on Chinese Botanical Works, Foochow, 1870, p. 29.

Now the Sea of Kadranj was entered, the *Perimulic* Gulf of Ptolemy. Among the coast names of the Greek record we may draw attention to *Samaradê*, and its coincidence with *Samarat*, the Buddhisto-classical name of the place commonly called Ligôr (i.e. '*Nagara*,' the city) on the eastern shore of the Malay Peninsula, subject to Siam; also to the river *Sobanus* (Skt. *Suvarṇa*, Palì *Sobana*, 'the Golden'), and to its synonymy with *Sobanapûri*, one of the old cities of Siam in the Menam basin.

The Arabs, as before, instead of coasting, struck across by another ten days' run to the port of *Kadranj*. Here was a high mountain to which slaves used to escape. I should identify Kadranj with the Ἀκάδρα (*Akadra*) of the Greeks, and place it about Chantabon. 'Here,' says Crawfurd (I quote from 'Ritter,' iv. 1069), 'at a short distance inland there stands a very high hill, Bombasoi, which affords from its summit an extensive view over Chantabon and Kamboja.' Between the Sobanus and Akadra the Greek coasting navigators also mention *Tipônobastê*, which would correspond to Bangpasoi of our maps, at the mouth of the large navigable river Bangpa-kong.

Ten days further (these *tens* are doubtless a little arbitrary or generalised, like the *ten days'* intervals of Herodotus across the Sahara[1]) the Arab navigators reach *Ṣanf* or *Chanf*, which under the limitations of the Arabic alphabet represents *Champa*, or the southern extremity of Cochin China, which I identify also with the Ζάβα or Ζάβαι of the Greeks.

It is true that Champa, as known in later days, lay to the east of the Mekong Delta, whilst Zabai of the Greeks lay to the west of that and of the *μέγα ἀκρωτήριον*—the 'Great Cape,' or C. Cambodia of our maps. Crawfurd ('Desc. Dict. Ind. Arch.,' p. 80) seems to say that the Malays include under the name *Champa* the whole of what we call Kamboja. This may possibly be a slip. But it is certain, as we shall see presently, that the Arab Ṣanf, which is unquestionably = Champa, also lay west of the Cape, i.e. within the Gulf of Siam. The fact is that the Indo-Chinese kingdoms have gone through unceasing and enormous vicissitudes, and in early days Champa must have been extensive and powerful, for in the travels of Hwen' T'sang (about A.D. 629) it is called *Mahâ*-Champa. And my late friend, Lieut. Garnier, who gave great attention to these questions, has deduced from such data as exist, in Chinese annals and elsewhere, that the ancient kingdom which the Chinese describe, under the name of *Fu-nan*, as extending over the whole peninsula east of the Gulf of Siam, was a kingdom of the *Tsiam* or Champa race.[2] The locality of the ancient port of Zabai or Champa is probably to be sought on the west coast of Kamboja, near the Campot or the Kang-Kao of our maps. On this coast also was the *Ḳomar* and *Ḳamârah* of Ibn Batuta and other Arab writers: the great source of aloes-wood—the country, then, of the *Khmer* or Kambojan people.

From Ṣanf the Arabs sail ten days again to an island (but evidently, from the plural form of the name, a *group* of islands) called *Sandar-Fulât*, where they find fresh water. We cannot hesitate to identify this with *Pulo Condor*. Marco Polo, in the name which he gives to the group, 'Sondur and Condur,' has furnished a link, if it be needed, to complete the identification. These may also be the 'Satyrs' Islands' of Ptolemy, or they may be his *Sindai*, for he has a *Sinda* city on the coast close to this

[1] *Herod.* iv. 181–183.

[2] See *Carte des Lieux Historiques de l'Indo-Chine, &c.*, at p. 128 in vol. i. of *Voyage d'Exploration*.

position, though his Sindai islands are dropt far away. But it would not be difficult to show that Ptolemy's islands have been located almost at random, or as from a pepper-castor.

We have said that the Arab *Ṣanf*, as well as the Greek *Zabai*, lay west of Cape Cambodia. This is proved, by the statement that the Arabs on their voyage to China made a ten days' run from *Ṣanf* to Pulo Condor.

Now they enter another sea, which they call the Sea of *Ṣanjî*, crossing which they enter the narrow passages and estuaries called the 'Gates of China.'

In Ptolemy the distance from Zabai to the Sinae is not determined. According to Alexander, as quoted by Ptolemy after Marinus, 'the land beyond the Golden Chersonnese lay facing the south, and sailing by this for twenty days you reach the city of Zabai, and, still sailing on for some days southward, but rather to the left, you reach *Kattigara*' (the port of the Sinae). The expression 'southward, but rather to the left,' is easily accounted for, if we recollect what has just been said of the position of Zabai on the west coast of Kamboja. Alexander *must* precisely have run 'south, but rather to the left,' for some days before turning north into the China Sea.

But no doubt Ptolemy, from his preconceptions of the general geography, necessarily misconstrued the further track of Alexander, and may have failed to quote some further indication. Regarding the Indian Ocean as a closed basin he is compelled to place the *Sinae* on the imaginary eastern shore of that basin. But we know, of course, that the sea is not a closed basin, and that the *Sinae could not* have lain south of Zabai and of the Great Cape, unless we are prepared, with a learned German, to put them on the west coast of Borneo!

I should say here that I consider it as unreasonable to explain *Sinae* by any name but Chinese, as it would be to explain *Indoi* by anything but Hindoos or Indians. *Sinae* does not require to be demonstrated to be Chinese; it *is* Chinese, just as much as *Français* is French or *Espagnols* Spaniards. But where lay Καττίγαρα ὅρμος Σινῶν—'*Kattigara*, the port of the Chinese'—is another question.

When I drew the map of Ancient India, with its elucidations, for Dr. W. Smith's Classical Atlas, though saying that I saw no means of determining the position of *Kattigara*, I was still inclined to believe that it was on the coast of China proper, either of Fokien or of the Yangtse Delta. But there was always some misgiving that the Ptolemaic statement was briefer and vaguer than would have been probable had the voyagers actually reached the swarming hive of the Central Flowery Kingdom. And to myself the arguments adduced by my friend Baron F. von Richthofen in favour of the location of Kattigara in the Gulf of Tongking are absolutely convincing. This position seems to satisfy every condition. For:

1. Tongking was for some centuries at that period (B.C. 111 to A.D. 263), and at that period only, actually incorporated as part of the Chinese Empire.

2. The only port mentioned in the Chinese annals as at that period open to foreign traffic was Kiau-chi, substantially identical with the modern capital of Tongking, Kesho or Hanoi. Whilst there are no notices of foreign arrivals by any other approach, there are repeated notices of such arrivals by this province, including that famous embassy from 'Antun, King of Ta-t'sin', i.e., M. Aurelius Antoninus, in A.D. 166.

3. The province in question was then known as Ji-nan (or Zhi-nan, French *J*); whence possibly the name *Sinae*, that has travelled so far and spread over such libraries of literature. The Chinese annalist, who mentions the Roman Embassy, adds: 'The people of that kingdom (*Ta-t'sin*, or the Roman Empire) come in numbers for trading purposes to *Fu-nan*, Ji-nan, and Kiau-chi.' Funan, we have seen, was Champa or Zabai. In Jinan, with its chief port Kiau-chi, we may recognise with assurance '*Kattigara, portus Sinarum*.'[1]

Mr. Bunbury, in his most able and valuable 'History of Ancient Geography,' whilst admitting the force of my argument as to the identity of the ancient names *Sinae* and *Thin* with *China*, observes: 'It does not appear to me necessary, therefore, to assume that the land so called was actually a part of the modern China. How easily the name might be extended to other regions in that part of Asia is sufficiently shown by the modern appellation of Cochin China, applied to the very country' in which he is inclined to locate the Sinae.

But neither he, nor I in my former consideration of this subject, had taken account of the facts adduced by Richthofen as to the incorporation at that time of Tongking with the Chinese Empire, and as to the recognition at that time of Kiauchi alone (as far as is known) as a gate of access for Western trade to the Empire. Richthofen's solution has the advantages of preserving the true meaning of *Sinae* as 'the Chinese,' and of locating the *Portus Sinarum* in what was then politically a part of China, whilst the remote metropolis *Thinae* remains unequivocally the capital of the Empire, whether Si-ngan-fu in Shensi, or Loyang in Honan, be meant.

I will only add that though we find *Katighora* in Edrisi's Geography, I apprehend this to be a mere adoption from the geography of Ptolemy, founded on no recent authority. It must have kept its place also on the later mediæval maps; for Pigafetta, in that part of the circumnavigation where the crew of the *Victoria* began to look out for the Asiatic coast, says that Magellan 'changed the course . . . until in 13° of N. Latitude, in order to approach the land of *Cape Gaticara*, which cape (under correction of those who have made cosmography, for they have never seen it) is not placed where they think, but is towards the north, in 12° or thereabouts.[2] It is probable that, as Richthofen points out, *Kattigara*, or at any rate, Kiau-chi, was the *Lûkin* or *Al-Wâkin* of the early Arab geographers. But the *terminus* of the Arab voyagers of the ninth century was no longer in Tongking; it was *Khânfû*—apparently the *Kanpu* of

[1] The name (*Kattigara*) seems (in form) Indian, like so many others on the route to the *Sinae*,—e.g., *Sobana*, *Pagrasa*, *Samaradê*, *R. Sobanus*, *Tiponobastê*, *Zaba*, *Tagora*, *Balonga*, *Sinde*, *Aganagara*, *Brama*, *R. Ambastus*, *Rabana*, *R. Kottiaris*, *Kokkoronagara*, etc.

'At first sight the identification of some of these names with names still adhering, or traditionally preserved, seems hazardous. But note that most of the names just recited are unquestionably Hindu. Hence it is a fact that Hindu names attached to places in Indo-China before the time of Ptolemy. It is another fact that many Hindu names attach now—e.g., *Singapore*, *Patani*, *Ligor*, *Yuthia*, *Champa*, *Suphana*, *Chantibon* (probably). Why should not the same name in some cases have survived?—' Sources and Authorities for India,' in Dr. Smith's *Atlas*.

[2] *The First Voyage round the World* (Hak. Soc.) translated by Lord Stanley of Alderley, p. 68. The translator too hastily (as elsewhere) explains: 'Cattigara. Cape Comorin in 8° 27′ 1″ North Lat.' The cape looked for was evidently the extreme S.E. point of Asia, actually represented by Cape Varela, or Cape St. James, on the coast of Cochin China.

the Chinese, the haven of the great city which we know as Hangchow, and which then lay on or near a delta-arm of the great Yangtse.[1]

The chief works of which I have made use in the foregoing (besides the original authorities named at the beginning, the Arabic ones in published translations, chiefly French), are Richthofen's 'China,' Bd. i. 1877; the same author's papers 'Ueber den Seeverkehr nach und von China in Alterthum und Mittelalter,' in the 'Transactions of the Berlin Geog. Society' for 1876; Sprenger, 'Post- und Reise-Routen des Orients,' Leipzig, 1864; A. Maury, 'Des Anciens Rapports de l'Asie occidentale avec l'Inde Transgangétique et la Chine,' in 'Bullet. de la Soc. de Géog. de Paris,' 1846; Mr. Bunbury's work just quoted; various notes of my own in 'Cathay and the Way Thither,' 'Marco Polo,' and the text to my map of Ancient India in Dr. W. Smith's 'Atlas of Ancient Geography.'

The Deserts of Africa and Asia. By P. DE TCHIHATCHEF, *Member of the Academies of Sciences of Paris, Berlin, Munich, St. Petersburg, &c.*

[A communication ordered by the General Committee to be printed *in extenso* among the Reports.]

THE large sandy surfaces which occupy immense tracts on our globe suggest naturally the belief of their being recently dried-up sea-bottoms, an impression enhanced by the presence of salt efflorescence and shells of still existing mollusks. It is therefore not surprising that the two largest deserts of the world, viz., the Sahara in Africa and the Gobi in Asia, have been, or are even sometimes now, considered as representatives of recently raised-up sea-basins. But the latest explorations tend to prove the contrary, at least as far as the Sahara is concerned, and the little we know of the great Asiatic deserts seems to lead to a similar result. My intention is, therefore, to submit a few considerations on the geological age of the following three deserts: the Sahara (the Lybian Desert included), the deserts situated in Turkistan between the Jaxartes and the Caspian Sea, and the Gobi of Central Asia.

Before speaking of the Sahara, I must observe that this collective name is applied to an immense region which forms a very broad strip across the whole of Africa, from the Red Sea to the Atlantic, occupying an area almost equal to the third of the African continent. This desert, the largest of the world, is dotted with oases, scattered on the sandy surface like so many islands amidst the sea, and is known only in the parts which belong to Algeria, Tunisia, and Tripoli (the last part being called the Lybian Desert), whereas the western portion of the desert is still a *terra incognita*; therefore, I ask you to remember that by the name of Sahara I mean only the more or less explored regions, adding, that what we know of them is most probably applicable to the unknown or little known tracts, the more so since they are almost exclusively composed of sand accumulation, the origin and the formation of which we are able to study in the Algerian and Lybian Deserts.

Since Algeria (which I visited two years ago) has been annexed to France, our knowledge of this country has made very rapid progress, so

[1] See *Marco Polo*, 2nd ed. ii. 181, 182.

that the ideas which were formerly entertained of the Saharan Desert have at present undergone an entire change. It has been ascertained that those sand-deposits, which completely hide the solid framework of the country, are comparatively local phenomena, and that in the greatest part of the Sahara-Lybian Desert the subjacent strata are perfectly conspicuous, either by cropping out through the superficial deposits, or by rising as mountains and hills, which almost all belong to the cretaceous formation, and cover an immense tract of this part of Africa. M. Rolland, who has particularly studied the cretaceous formation of the Sahara, speaks[1] with astonishment of its extraordinary development, not only in the French Sahara, where it occupies an area equal to that of all France, but also in the whole African Desert, touching the Red Sea on the east and the Atlantic on the west. 'For in all those regions,' says M. Rolland, 'cretaceous strata, containing the same fauna and having the same mineralogical composition, are developed on a line of 60 degrees in length, with 3 to 6 degrees in width. No later sediments repose on those rocks, with the exception only of some quaternary deposits, filling up, in the Lybian Desert, the depressions between the cretaceous mountains.'

The western extremity of this immense mountain range being situated in Marocco, cannot have been as well examined as the part crossing the French Sahara and the Lybian Desert, where the cretaceous formation is no less completely developed than in the northern regions of Algeria—regions which may be considered in this respect as truly classic ground; for the energetic explorations of M. Coquand have ascertained there all the known subdivisions of this formation, characterised by fossils more numerous and more various than perhaps in any country of a similar extent, the amount of new cretaceous species in northern Algeria being, according to him, no less than 227.

The regions of the Sahara not occupied by cretaceous mountains and hills consist of large surfaces, more or less horizontal, composed either of loose sands or diluvial (quaternary) deposits. These last seem to have formed gulfs which, after the emergence of the cretaceous masses, remained covered by the sea, and were filled up in a comparatively recent epoch, for they contain shells of mollusks belonging to still living species.

As for the rocks which underlie the sandy deposits, what we know of them is due to the numerous wells sunk by the French along the northern boundaries of the Sahara, particularly in the province of Constantine. The learned engineer, M. Jus, who during twenty years has directed those admirable works, ranges in the pliocene formation the different rocks (limestone, sandstone, marls, gypsum, &c.), pierced by the soundings, as well as the impermeable water-bearing clay which forms the bottom of the wells. This clay presents the most astonishing discrepancies in its level, being sometimes many hundred feet under the surface of the soil, and sometimes approaching it very closely. So, for instance, in the region of Wadi-Rir, two wells named Aïn-Kerma and Unel-Thiur, are distant one from the other about forty miles, yet the depth of the first is only 44 feet, and that of the second 321 feet. In the country of Honda, the well named Nemechdib is 10 feet deep, whereas the well Barika, almost close to it, is 117 feet. Again, at Batna and at Biskra, the soundings have been pushed through more than 540 feet, without reaching any subterranean water, so that the works were aban-

[1] *Comptes Rendus des Séances de l'Acad. des Sc.*, 1879, vol. lxxviii. p. 778.

doned, most unfortunately for those two cities, which are suffering from the want of good water. The same thing happened at Tahin-Bacu, where at the depth of 300 feet no water could be reached.

We must consequently admit that the pliocene impermeable clay, before having been covered first by different rocks, and finally by sand, has been exposed to some powerful agents which caused its surface to undergo the most various changes, so as to produce more or less deep excavations in some places, and to leave others (often quite near the first) in the shape of high conical masses, with hollowed basin-like tops.

Another curious phenomenon which the sinking of the Algerian wells has revealed is the discovery of fishes, crabs, and fresh-water mollusks, at considerable depths. This interesting fact has been ascertained in the artesian well called Mezer, situated in the desert of Wadi-Rir, quite near one of the brackish lakes (*Chott* or *Sebkha* of the Arabs), which are so numerous in the region between Biskra and Tuggurt. When the sounding-line brought those creatures from a depth of about 230 feet, they were perfectly alive, and M. Jus even boiled a crab, and found it of excellent taste. The fishes were covered with sand and mud, but the shell of the crabs was quite bright and glittering, a proof that they inhabited pure water. M. Jus showed me all these animals, preserved in spirit, and adorning his rich collections at Batna.

The wells constructed by the French engineers numbered at my last visit (1879) in the province of Constantine alone (and there are many elsewhere) more than 155; and as the works begun in 1856 have never been interrupted, and are rapidly advancing into the interior of the desert, the time may not be far off when all these regions, now so barren and dry, will be copiously irrigated, an advantage which they certainly enjoyed once, seeing that the numerous oases spread over the Sahara and the Lybian desert contain many remnants of Greek and Roman constructions; a proof that once they were populated and consequently provided with water. This was most probably got by means of the so-called artesian wells, which we moderns presume to consider as our own invention, whereas they were undoubtedly known to the ancients, and were even constructed in the very Desert of Sahara, as it is ascertained from Olympiodorus, an historian whose writings have perished, with the exception of a few fragments quoted by the learned Greek patriarch Photius, one of which contains the following important passage: 'In the oasis of Sahara the inhabitants used to scoop out excavations 100 and 250 feet deep, from which jets of pure water rose in high columns.' But it was not in the Sahara alone that the ancients sunk artesian wells, they multiplied them almost everywhere; and to those artificial irrigations was due the once flourishing state of the plain now so arid, which is covered by the ruins of Balbek (the ancient Heliopolis) and Palmyra. The English travellers, Wood and Darwin, discovered under those heaps of ruins numerous traces of ancient artesian wells; and such traces are so frequent in the Arabian desert crossed by the Hebrews under the leadership of Moses, that several modern authors, among others M. Joberd, are of opinion that the miracle attributed to the celebrated Hebrew legislator of having called forth a jet of water from a rock he struck with his staff, may be explained by the presence of an artesian well previously known to him.

Since the invasion of the destructive Ottoman race, all those monu-

ments of ancient civilisation have disappeared, and it is the glorious task of France to make them revive once more in Algeria. Her exertions have been crowned with success, and, without mentioning any of the numerous improvements which this country has received, and which really have transformed it in a most marvellous way,[1] the creation of the admirable network of artesian wells established on a line of about 500 miles of length, and penetrating every day deeper in the desert, would be quite sufficient to secure to France a prominent place in the history of civilisation, infinitely superior to that occupied by her most splendid conquerors.

The annexation of Algeria is one of those events which philosophers and philanthropists must hail with joy; to them it matters very little if countries rescued from the iron hands of barbarism and restored to civilisation may be called Cyprus, Algiers, Tunis, Herat, Alexandria, &c., or if the resurrection of such countries is promoted by a Latin, German, or Slavonian race; all those petty national distinctions and susceptibilities vanish before the eternal tribunal of humanity and Christianity, which bestows the laurels of the conqueror only on the deliverer and restorer of oppressed nations.

The artesian wells of Algeria suggest still many other scientific considerations, but I will limit myself to a few words upon the probable origin of the subterranean waters which feed these wells, and of the enormous sand-accumulations which cover the deserts.

In the Lybian desert, which is only the eastern continuation of the Sahara, Dr. Zittel is of opinion that between the oasis of Siwah (the seat of the famous temple of Jupiter Ammon, visited by Alexander the Great) and the Nile there is a large subterranean depression excavated in the impermeable clays and marls which compose the underground of the great part of the desert; the strata of the northern side of the depression dip to the south, so as to prevent the water gathered in it from escaping to the Mediterranean; those waters, which are furnished by the copious rains falling in the mountainous tracts of Central Africa, penetrate until they reach the impermeable clays, and in this way are carried to the above-mentioned natural reservoir. The supposed stratigraphical conditions of this depression have been suggested to the German geologist by the sections which he observed in the oasis Beharrich, situated near the Siwah oasis, where the strata of clay and marl are perceived to dip to the south.

Some such natural reservoir may exist equally in the Sahara, but as far as I am aware nothing of that kind has been yet ascertained there, so that in the present state of our knowledge we are reduced to the supposition that its subterranean waters are chiefly produced by the rains in the mountainous country forming its northern boundary, among which the Aurès range plays an important part. Most probably the water furnished by those mountains (for in the Sahara itself rain is very rare) oozes through the different open crevices, joints, vaults, etc., and penetrates into the impermeable argillaceous strata. At any rate, the above-mentioned presence of fishes and crabs in the well of Mezer, prove that a communication between the atmosphere and the subterranean waters must exist, otherwise no animal (at least of the higher classes) could live there.

[1] This I have endeavoured to prove in my work *Espagne, Algérie et Tunisie*, Paris, 1880.

The last but not the least important geological element of the Sahara-Lybian desert, is the sand, which contains no organic remains, except at places where it is intermingled with underlying older diluvial deposits. Those enormous sandy accumulations doubtless are not of marine but of subaërial origin. Still their vast proportions render it difficult to decide the question whence they came and how they have been formed. Dr. Zittel, to whom we owe valuable observations on the Lybian desert, thinks that these accumulations of sand are on too large a scale to be explained by Baron Richthofen's theory of the formation of the Löss in China, though he concedes to the action of winds an important part in the African deserts also. In consequence Dr. Zittel admits that those sands have been transported not only by atmospheric movements but also by water-floods. And as the desert sands consist of quartz which could not have been furnished by the limestone and marly rocks prevailing in the desert, he supposes that it may have been derived from the so-called Nubian sandstone which composes the mountainous range situated in the southern part of the Lybian desert, and which, after long discussions among geologists, has definitely been placed in the cretaceous formation. Dr. Zittel thinks that the disintegration of this sandstone has been produced by water, the erosive power of which has left in the desert so many conspicuous traces, as, for instance, the high and steep sides of the oasis, the deep depressions, and particularly the isolated rocks he calls 'insular mountains,' considering them as the scattered remnants of once connected masses, so that, according to him, such gigantic denudations and erosions can only be the work of violent fresh-water floods coming from the south and carrying the large quantity of petrified tree-trunks so frequent in the Lybian desert. Several objections arise against this theory, at least as far as the Sahara is concerned, the southern boundaries of which are not composed, as in the Lybian desert, of sandstone, but chiefly of limestone, marls, and clay, and consequently could not furnish the quartz grains yielded by the Nubian sandstone. Moreover, the violent fresh-water floods proceeding from the south, which, according to Dr. Zittel, caused in the Lybian desert the above-mentioned enormous denudations and erosions, suppose an extraordinary change in the climate of that country; for, though Dr. Zittel admits that in Egypt, and consequently in the neighbouring countries, the atmospheric humidity was, at a comparatively recent epoch, much greater than now, such powerful floods could only be produced by rains unknown in the most rainy regions of our globe. At all events M. Rolland thinks that as far as the Sahara is concerned, the quaternary and alluvial sandstones which the desert contains are sufficient for the production of sand-accumulations, which, according to him, are derived from actual atmospheric agencies, namely, first, by disintegration, and then by the winds scattering the grains over the surface of the desert.

The hypothesis of the subaërial origin of those sands receives a strong support, as well from the facts ascertained in reference to the large distances to which such sands may be carried as from the comparative study of atmospheric sands fallen in different countries. Now, even in the twelfth century the celebrated Arab geographer Edrisi spoke with astonishment of the clouds of red dust and dry fog which frequently obscured the sky of the Atlantic between the Green Cape and South America, a tract which Edrisi qualified for that reason as the Dark Sea (*Bar-el-Mecdolin*), and after him the authors of the middle age as *Mare*

tenebrosum. This phenomenon, which has occupied for a long time the attention of physicists and naturalists, whose opinions are as contradictory as unsatisfactory, has been recently studied by Dr. Gustav Helleman, who, in an elaborate work, gives not only a chronological enumeration of all the observations published on that subject from 1854 to 1874, but represents them graphically on a most instructive map. The critical analysis of these numerous materials has suggested to the Prussian philosopher, conclusions on the origin of this curious phenomenon, thoroughly opposite to those hitherto deduced by all his predecessors, including the learned Ehrenberg. These conclusions are: that the above-mentioned clouds of dust proceed from the Western Sahara, and even partly from the French Sahara, for Dr. Helleman informs us that, having consulted the meteorological registers kept in the French stations of Laguat, Tuggurt, Wargla, etc., he ascertained numerous days marked in those registers as particularly characterised by Sirocco winds, accompanied by an atmosphere rendered dusty by sand.

Another observation in reference to the composition of sands transported by winds from various countries yielded equally remarkable results to Gustav Tissandier. Examining microscopically the dust which fell the 9th of October, 1879, at Boulogne-sur-Mer, and comparing it with the sand of the Sahara, he found that both were exactly of the same composition, only the last was of a coarser grain, and that the fragments of cryptogamic plants were in both identical. Moreover, the French physicist ascertained that when sand from the deserts of Sahara and Gobi was thrown into water, only the coarser particles fell to the bottom, and the water remained turbid in consequence of a certain quantity of thin mud swimming in it; this last, having been microscopically examined, turned out to be very like certain earthy particles contained in rain-water, which sometimes is so rich in organic substances that such rains have been qualified as *manure rains.* The result which Tissandier deduces from repeated experiences is, that 'the winds bring about a real selection of the smallest and lightest bodies of the desert, upraising in the air only the minutest particles, among which are the vegetable remnants, so that the atmospheric movements may convey a dust very rich in organic substances, even when they have been borrowed from a sand containing little of them, and that only because the selection has been applied to large masses.' This curious observation may suggest the inference that, at least in certain places, the sand of deserts is not so barren and hostile to vegetation as it at first appears. At all events, the absence of any animal traces in the Sahara and Gobi sands examined by M. Tissandier, proves most evidently their subaerial origin, for had they been deposited in sea-water they would include numerous microscopic shells of Rhizopoda, which are so abundant in sea sand, that Alcide d'Orbigny counted in one ounce of sand gathered in the Antilles Islands, more than three millions of them; and similar facts may be ascertained in Europe, where, among other littoral regions, the sand of the Adriatic shores contains numberless quantities of Rhizopodous shells.

Again, M. Tacchini attributes an African origin to the highly ferruginous dust which not long ago fell in many places in Italy. What seems to indicate such an origin is the fact that numerous globules of magnetic iron have been found along the shores of Algeria and Tunis. The Italian astronomer observes, that this fact has a certain importance, for it would prove that in some cases a terrestrial but not a cosmical origin may be

ascribed to the meteoric iron globules which occur in the sand of remote localities, and under the most different conditions, as, for instance, in snow.

These sandy superficial deposits form the last chapter of the geological history of the Sahara, for, so far as I know, no well-ascertained traces of the glacial period have been discovered either in Algeria or in the Sahara-Lybian desert, so that the absence of the glacial period in those parts of Africa furnishes an additional proof of the *local* and comparatively *limited* character of this important phenomenon, a fact on which I have repeatedly insisted in numerous publications.[1]

But if after the formation of the superficial sandy masses the Sahara had acquired the most prominent features of her present physiognomy, still, since that time, not only the hydrographic and climatic, but also some topographic conditions of that country have undergone very important modifications, as may be deduced from many facts, among which I will mention only those pointed out by Rolland and Clavé. The first calls our attention to the numerous incrustations of travertine, evidently produced from sources which have disappeared, and to the immense quantity of siliceous fragments worked and shaped by human hands, and scattered about large tracts of the desert, where it is not likely that they could have been distributed, if the now uninhabitable country were not once inhabited. M. Rolland sums up the conclusions derived from a great number of similar facts in the following words: 'The climate of Algeria must have suffered a considerable deterioration since the times of the Romans.' M. Clavé is of the same opinion. He mentions with astonishment the quantity of fragments of arrows made of polished flint, scattered over the whole space between Biskra and Wargla; and what is still more significant, he has observed in the neighbourhood of Oglu-el-Kassi, those fragments covered by a coating 16 inches thick of gypsum, evidently deposited by sources of which all traces have vanished. 'Those flint-fragments invested by gypsous incrustations,' says M. Clavé, 'are most probably the oldest known witnesses of human industry.' Now, the Lybian desert yields to Dr. Zittel exactly similar conclusions. The learned German geologist observes that between the oasis Chargeh and the valley of the Nile, the basaltic tufa include leaves of plants, among others, of the evergreen oak (*Quercus ilex*), which no longer exist either on the oasis or in Upper Egypt. 'Caves bristling with stalactites in a country perfectly devoid of water,' says Dr. Zittel, 'but particularly the polished and well-worked flints accumulated on different points of the now thoroughly dry and empty desert, speak distinctly of a much more favourable climate than the present one.'

No doubt such climatic changes ascertained in the Sahara-Lybian desert must suppose similar changes in the countries surrounding the Mediterranean basin, as among others: Egypt, Syria, Asia Minor, &c. And that is really the fact; the arguments supporting it being as numerous as convincing. It would not be consistent with the limits imposed on this paper to mention even a small number of them, so that I must content myself with the following observations.

In his remarkable work on the climate of the Mediterranean countries,[2] Theobald Fischer, after having studied the changes which they

[1] *Une Page sur l'Orient*, pp. 251–272; *La végétation du Globe*; *Espagne, Algérie et Tunisie*, pp. 429 et seq.

[2] *Studien über das Klima der Mediterraneen Länder*, in Petermann's *Mittheilungen*, 1879.

have undergone on that account during historic times, comes to the conclusion that such changes have not been very conspicuous in the regions of the northern shores of the basin, where the climatic modifications, which I had pointed out in Asia Minor, are considered by him as only local and exceptional phenomena, but that it is quite different in the regions situated on the southern shores of the Mediterranean, to the south of the 34th parallel, where rains, even in their normal state, are so inconsiderable, that the smallest reduction of their amount is sufficient to alter the climate. Among the countries liable to such reductions, Fischer quotes Syria and Palestine, countries full of traces of ancient rivers and artificial irrigation, indicating a region once thickly populated, but which now is transformed into a dry desert, not only by the fault of men, but also in consequence of a complete change in the atmospheric conditions. Fischer also points out the numerous deeply excavated *Wadi* in the whole of Africa, which doubtless represent so many beds of ancient rivers, in a time when rains were much more frequent than now. This important fact had been (many years before the publication of Fischer's work) elucidated and discussed, in a masterly way, by Livingstone.[1]

According to Fischer, the increase of the atmospheric dryness in North Africa is equally proved by the disappearance of the large mammals and the late introduction of the camel in those regions. This animal, now quite indispensable for all travelling purposes, seems to have been unknown in Africa almost until the Christian era, for no figure of it has hitherto been discovered on the monuments of Egypt and Meroë, and Polybius, speaking of the Carthaginian cavalry, mentions elephants but never camels. I had previously the opportunity of pointing out this interesting fact in Asia Minor,[2] quoting numerous classic authorities, and among others Herodotus and Xenophon, who both attribute the victory of Cyrus, in the battle of Sardes, over the Lydian king, to the presence in the Persian army of camels, the sight of which struck the Lydian cavalry with terror and made them fly. Even in the sixth century of our era, the historian Procopius mentions a similar impression produced on the Roman cavalry by the sight of the camels employed in the Arabian army; but what is still more remarkable is, that as late as in the twelfth century, Glycas reporting in his 'Annals' the battle of Sardes, together with the statements of Herodotus and Xenophon, in reference to the impression produced by the Persian camels, does not add to this quotation any remark upon the difference between the habits of the camels of the ancient and those of his time, which seems to prove that he did not find anything extraordinary in such statements, and that consequently even in the twelfth century, the camel had not acquired in the East the perfect indifference it now shows for horses, which I have often experienced, keeping camels and horses tied up together without causing either the least annoyance.

Theobald Fischer quotes the authority of Herodotus and Pliny, and also many ancient monuments adorned with animal figures, in order to prove that in historical times North Africa was inhabited by the elephant and rhinoceros, and, what is still more significant, by crocodiles; for those amphibians suppose the existence of rivers not liable to be dried

[1] *The last Journals of David Livingstone in Africa*, &c., by H. Waller, London, 1874, vol. i. p. 215–220.

[2] Tchihatchef, *Asie Mineure, Climatalogie et Zoologie*, p. 757.

up. It is impossible to attribute the disappearance of all those animals only to the action of man; the less so as the countries where they have been mentioned were infinitely more populated than they now are, and therefore offered to wild beasts a less favourable abode than now. We are consequently compelled to admit an alteration in the climatic conditions of the country, namely, an increase of atmospheric dryness, which may account for the late introduction of the camel in North Africa and Asia Minor, as well as for the disappearance of the elephant. In support of this opinion, Theobald Fischer reminds us, that both in Asia and Africa the elephant excludes the camel, and *vice versâ*, so that in the upper part of the valley of the Nile, where the elephant prospers, the camel thrives with difficulty.

Dr. Oscar Fraas, the learned German geologist, also quotes[1] the absence on the Egyptian monuments of any figure of the camel, and that not only in the famous ruined city Sakkarah, the walls of which are covered with pictorial representations of different animals, but also in Thebes, founded 3,000 years after Sakkarah. This fact proves that at that time the desert did not exist, the presence of which is moreover excluded by the numerous splendid monuments, which certainly their constructors would not have built in the midst of inhospitable solitudes, any more than the Emperor Hadrian would have erected near Rome the famous Villa Hadriana amidst marshes, had they existed then as now. Oscar Fraas is of opinion that in Egypt the climatic conditions were quite different from the present, even in the time of the Greeks, when Alexandria was the brilliant focus of science and art, radiating her light on the whole world then known. He believes that the extraordinary intellectual activity which animated this city, supposes another climate, with a moister air. 'On the present soil of the Nile land,' says Oscar Fraas, 'no philosophical system can be born, and no human power could erect universities capable of coping with those of Europe.'

The conclusions suggested by Egypt are applicable in a still higher degree to the neighbouring peninsula of Sinai. When we consider that in this perfectly arid, waterless peninsula, the people of Israel, counting 60,000 fighting men, remained, after the exodus from Egypt, several years, it becomes quite impossible not to admit that in those times Sinai was a fertile Alpine region, provided with rich pasture-grounds and irrigated by copious sources: in no respect could such a country have the slightest resemblance to the barren desert it is now.

The few instances I have reported are sufficient to prove that the climate of the Sahara-Lybian desert, as well as that of the countries surrounding the Mediterranean, have really undergone important alterations, even during historical times. Now there are proofs that similar changes in the level of the ground and in the vegetation of these regions have taken place at a comparatively recent epoch. Theobald Fischer, whom I have already had occasion to quote, has devoted to the study of the topographical modifications of the Mediterranean countries the same talent and erudition with which he has treated the question of the successive climatic changes which have occurred there. In his paper, published by the Geographical Society of Berlin,[2] he elucidates this subject in a masterly way, and the map annexed to his paper represents graphically

[1] *Aus dem Orient: geologische Beobachtungen am Nil, auf der Sinai-Halbinsel und in Syrien* (Stuttgart: 1867), pp. 214–216.

[2] *Zeitschrift der Gesellschaft für Erdkunde zu Berlin*, 1878, vol. xiii. p. 151.

the numerous alternate immersions and emersions positively ascertained in the littoral regions of almost all the countries surrounding the Mediterranean. On the African shores this phenomenon is particularly striking, as much by its intensity as by the variety of its manifestations, the movement of the rising and the sinking of the soil occurring alternately on the same littoral line, in localities not far distant the one from the others. Gerhard Rohlfs, the well-known African explorer, has ascertained the sinking of the whole shore of Tripoli to the Gulf of Great Syrtis, and, according to him, this sinking is so conspicuous that he was perfectly able to appreciate it during his repeated visits to the country. He quotes very remarkable instances of this phenomenon and says: 'I do not think that anywhere on our globe such a rapid sinking of the soil has ever been observed.'

Now, a quite opposite movement of the soil occurs in the neighbouring Tunisian shores. Here M. Barth has discovered near the modern town of Gabès ruins of a much older one, which he identifies with the ancient city *Tascape*, a city situated, according to the Greek and Roman writers, on the sea-shore, which is no more the case with the modern Gabès. Sir Granville Temple has observed traces of an ancient gulf penetrating from Gabès in the interior of the continent, and connected with the lake or Chott el Fedjedj (the ancient *Tritonis lacus*), a connection which has been interrupted by the rising of the tract, which, under the shape of an isthmus, now separates the Gulf of Gabès from the lake. Nearer Tunis we find the bay of Porto Farina, which, two centuries ago, was considered as an excellent port, 30 to 50 feet deep, so that in the year 1655 Admiral Blake could very comfortably anchor there, with his naval force, composed of nine men of war. At present, the Porto Farina has hardly a depth of 2 feet, and the time is not far off when the whole bay will be joined to the continent. Again, the celebrated city of Utica, which, under the Carthaginians, possessed a splendid port, is now converted into a large sandy plain, and the ruins of the once littoral city are more than twelve miles distant from the sea. There are few places in the world which offer a more melancholy contrast between the present and the past than this sandy, perfectly shadeless plain, which I crossed under the scorching African June sun, without meeting a single living creature, and which recalled similar impressions in the classic regions of Asia Minor, where not only man, but also Nature, has for so many centuries practised the work of destruction. But if Nature destroys she equally creates, and in a topographical sense Asia Minor offers, on that account, the most striking examples. During the ten years I devoted to the exploration of that magnificent country, I was able—the ancient geographers and historians in my hand—to ascertain the modifications which the surface of this country has undergone, only since the Christian era. Those modifications are so considerable, that taking into account the increase of solid land, produced only by the formation of large river deltas, and the filling up of seas and gulfs, it can be said, without exaggeration, that the surface of Asia Minor has conquered, during this comparatively short time, the amount of a little province, a kind of conquest which is still rapidly continuing, so that one day may be realised the prophecy of Strabo, who, eighteen centuries ago, declared that the time shall come when the shores of Cilicia may reach the island of Cyprus, an event likely to give great trouble to diplomatists, if such functionaries are then still existing.

To those remarks on the different physical changes undergone by the Sahara-Lybian desert and the Mediterranean regions during the latest geological periods, and even historical times, I may add a few words about some botanical modifications, which probably took place after the formation of the Mediterranean Sea, considered by several naturalists as comparatively recent. The fact is, that the two shores of this Sea present a great difference in the amount and the distribution of certain vegetable families, a difference which climatic conditions are not sufficient to explain. Among those vegetable families I will quote only the *Cupuliferæ* and the *Coniferæ*. In the first, the genus *Quercus*, or oak, is particularly conspicuous on that account. In geological aspect the oak may be considered as of recent origin, for among the thirty-four species admitted by Count Saporta, all, with the exception of one only (*Quercus primordialis*), appear, for the first time, as late as in the more recent tertiary formations (miocene and pliocene). Now, Algeria has hardly nine species of oak, but Spain, sixteen species; France, twelve; Greece, probably more than fifteen; whereas Asia Minor, where the genus seems to have acquired its maximum of development, has fifty-two species, of which twenty-six are peculiar to the Anatolian peninsula.[1]

As for the family of *Coniferæ*, the cedar presents a striking example of localisation, for, on the whole Mediterranean coast-line, there are only four points where this beautiful tree grows truly wild, viz., the Lebanon (Syria), Algeria, Cilicia (southern Asia Minor), and Cyprus; the existence of the cedar in that last island having been recently ascertained by Sir Samuel Baker. The Lebanon had been considered as the cradle of the cedar, before North Africa was known to contain large forests of a variety of that species (*Cedrus Libani*, var. *atlantica*), but the Austrian botanist Kotschy and I were so fortunate as to discover in Cilicia a new locality for this fine tree, much more important than any known previously, as I believe to have proved,[2] when comparing the Algerian cedar forests with the Anatolian, so that if these last had been known when the botanist Loudon established the new species of cedar, he would have called it *Cedrus Ciliciæ* instead of *Cedrus Libani*.

The two instances of curious localisation, which I have just alluded to, are sufficient to prove that such phenomena took place after the formation of the Mediterranean Sea; for had the cedar been spread out on the continent which once united Europe to Africa, this tree must have remained, after the separation of the two continents, on many points of the northern shores of the Mediterranean, as, for instance, on the mountains of Greece, on the Apennines, the Pyrenees, &c., where the conditions of climate and soil are as favourable to the cedar as they are in North Africa, Asia Minor, or on the Lebanon; whereas, if we admit that the cedar appeared on its present stations after the formation of the Mediterranean, the impediments opposed by the sea to the diffusion of the tree on both sides of the Mediterranean account sufficiently for its localisation.

A similar reasoning may be applied to the absence of monkeys on the northern shores of the Mediterranean, and their abundance on the southern. It is known that the only point in Europe inhabited by wild monkeys is the rock of Gibraltar; still they are there by no means indigenous, but most probably have been imported by the Arabs during

[1] Tchihatchef, *Asie Mineure, partie botanique*, vol. ii. pp. 463–480.
[2] *Espagne, Algérie et Tunisie*, p. 78.

their long domination of Spain, so that had this interesting colony not been artificially maintained, there would be now-a-days not a single monkey on this rock; the fact is, that in 1856 they had almost entirely disappeared, when Sir William Codrington caused a new importation to be made from northern Africa. Just as the cedar, the monkeys of Gibraltar (the *Macacus inuus* of Algeria) would be found now as indigenous inhabitants on many shores of Greece, Italy, Spain, &c., had they existed before the separation of Europe from Africa. An additional proof of the recent immigration of the monkey in Africa is, that the quaternary fauna of the caves of Gibraltar, so carefully studied by English geologists (Busk, Smith, Leith Adams, &c.), has not yielded any remains of quadrumana; and A. R. Wallace admits[1] that, even at the Miocene epoch, monkeys as well as the large mammals now characteristic of Africa (lion, elephant, hyæna, rhinoceros, hippopotamus, &c.) were spread over Central Europe, but still did not inhabit Africa, into which they migrated at a comparatively recent time.

I will here conclude my very rapid physical sketch of the Sahara-Lybian desert by a summary of the most prominent features of the geological history of that country; but before doing it, I wish to say a few words about the important scheme of the creation of an inland sea in the Sahara, which has been proposed to the French Government by Commander Roudaire. As I have fully discussed the question in my last work upon Algeria,[2] I will content myself only with the following remarks.

The project of this distinguished engineer consists of introducing the water of the Gulf of Gabès into the interior of Tunisia and Algeria, by cutting through the isthmus which separates the gulf from the large lake El-Fedjedj (*Tritonis lacus* of the ancients), situated under the sea-level, as are a whole series of lakes (*Chotts*) extending in a direct line from east to west, from the El-Fedjedj far into the interior of Algeria. Now, Commander Roudaire thinks that the consequence of cutting the Isthmus of Gabès, the breadth of which is about 18 miles, would be to spread the sea-water over a space of about 380 miles (320 kilomètres) of length from east to west, and about 70 to 80 miles (50 to 60 kilomètres) of breadth. The chief result of such a work would be, according to Commander Roudaire, a great improvement in the climate of this part of Sahara, because this large water-surface would give rise to an enormous evaporation, which, transported by the south, south-east, or south-west winds, into the northern regions of Algeria and Tunisia, must needs become condensed in passing over the Aurès Mountains, and be dissolved in copious rains. Moreover, Commander Roudaire declares that the creation of this large gulf or inland sea would be nothing else than the re-establishment of what has previously existed; for, supported by the authority of Ptolemy and other ancient geographers, he believes that formerly the Isthmus of Gabès did not separate the sea from the lake of Tritonis (El-Fedjedj), and that, consequently, the sea penetrated very far into the interior of the Sahara.

At all events, the chief point on which the success of the whole enterprise depends is the question, whether the prevailing winds in this part of

[1] *Quart. Journ. of the Geol. Soc.* 1878, vol. xxxiv. p. 34.

[2] Loc. cit. pp. 539–551. M. Cosson has just published upon that subject an important work entitled: *Sur le Projet de création en Algérie et en Tunisie d'une mer intérieure.*

the Sahara are really from the south; for if not, the winds, instead of carrying the aqueous vapours to the north, would drive them in the opposite direction—to the Sahara—without submitting them to the condensation produced by the Aurès Mountains, so that the creation of the large mass of vapours would be of no benefit at all to the country. Unfortunately this most important meteorological question is still very far from being decided; indeed, many scientific men in France admit that at Biskra and Tuggurt the north-west, north-east, and north winds are prevalent.

As for the statement that the Gulf of Gabès communicated formerly with the Tritonis lacus (El-Fedjedj) and penetrated deeply into the interior of the Sahara, this statement of Commander Roudaire, which has been strongly attacked both in France and Germany, is, as I think to have proved,[1] perfectly founded and abundantly supported not only by historical but also by geological facts.

Let us now resume, in a few words, the most prominent features of the geological history of the Sahara-Lybian desert.

1. The records of this history are very old, for the southern region of the present Sahara was represented during the Devonian period by a certain number of isolated masses of limestone, gneiss, and mica-schist, the limestone containing Devonian fossils. Those masses preserved their insular position through all the succeeding ages, and never sank again under the sea.

2. It was during the cretaceous epoch that a large portion of the present Sahara was upheaved in the shape of variously ramified masses, so that the sea of the following geological periods could penetrate into their interior, forming numerous gulfs and bays.

3. The Sahara was represented down to the quaternary epoch chiefly by those cretaceous masses which since their upheaval have never been covered by the sea. During the quaternary period, among the gulfs which washed the shores of the cretaceous land, the largest occupied the present country of Igharghar; the northern extremity of that gulf reached the place of Biskra, and the southern the cretaceous plateaux of Tademayt and Tinghert; the town Wargla occupying almost the central part of the gulf. As the last was entirely secluded from any communication with the sea from the north, the littoral part of Algeria having been upraised long before, and consisting then, as now, of more or less high mountains, this large quaternary gulf could not find any other way into the interior of the Saharan cretaceous continent than through the present Gulf of Gabès; and the narrow strip of diluvial deposits which, surrounded by cretaceous rocks, extends from Gabès to the salt lake of El-Fedjedj (Tritonis lacus) proves that here was really the entrance of the quaternary gulf. This geological fact is important with reference to the question, so long discussed, of the ancient communication between the lake and the sea; it confirms the hypothesis of Commander Roudaire, and I am not aware that this argument, which I consider as the strongest of all, has ever been urged in his favour. The upheaval of the quaternary large gulf (and of many other smaller ones) was the last marine phase which the Sahara underwent.

4. Once entirely raised up in all its parts, the Sahara had still to undergo a subaërial operation which consisted of the formation and

[1] *Loc. cit.* p. 541.

accumulation of sands. It closes the fourth and last stage of its long geological history, without speaking of the different climatic and topographical modifications of quite recent times. This history, as it has been shown, proves that there can be no longer question of a recent rising of the whole Sahara from the bottom of the sea. It is true the Lybian desert is probably somewhat younger than its Saharan sister, for tertiary uncovered deposits (eocene and miocene) have there a larger development than the cretaceous strata; but, even admitting that the Lybian desert has been upraised after the Miocene period, it cannot be called recent.

If I have perhaps devoted to the Sahara-Lybian desert more time than I ought to have done, it is because, among the chief deserts of Africa and Asia, this is by far the best known, so that I have only a few words to say about the Turkestan deserts and the Gobi.

The two largest deserts of Turkestan are situated between the Syr Daria (*Jaxartes*) and the Caspian Sea—roughly speaking, between the 45th and 48th degrees of northern latitude, and consequently under the parallel of North Italy and Switzerland. The one—the more eastern—named Kizyl-Kum (signifying in Turkish 'red sand'), is included between the Syr Daria and the Amu Daria (*Oxus*); it is limited on the north-west by the Aral Sea, and extends in the southern direction to Bokhara, having from north to south a length of about 400 miles, and from east to west about 300. The other desert, almost of the same development, is situated between the Amu Daria and the Caspian Sea, and extends from the country of Khiva to near that of Merv; the Turcomans generally call it Kara-Kum (black sand).

I have not visited either of these deserts during my long ramblings in the East, and I am not aware of anything known as far as their geological constitution is concerned. A short notice, however, published about them in the valuable geographical contributions of Petermann,[1] contains a few facts which may throw some little light on that subject. The sands which cover certain parts of the desert are reported as including shells of mollusks still living in the Aral Sea, but where sands are wanting, clay slates (*Thonschiefer*) form perfectly uncovered surfaces. Very good water is found everywhere under the sand at a depth of less than a foot, but it is reached only at 2 to 4 fathoms in the clay slates, and is briny and bitter; this difference seems to prove that the sands contain much less salt than the clay slate, probably because the salt spread about among the light quartz particles is more easily diluted by the atmospheric waters than the salt contained in the compact rock of clay slate.

It is most probable that this clay slate belongs to the Palæozoic epoch, and that consequently the two Turkestan deserts have been upraised at a very ancient geological period. As for the sands containing remnants of mollusks still inhabiting the Aral Sea, they may have been, partly at least, deposited at a time when the Caspian and Aral formed a single water-sheet.

In the whole steppe designed by the collective name of Khirgis Steppe, of which the Kizil-Kum and the Kara-Kum form only a part, the climate offers the most violent contrasts. The heat begins in May, when the temperature rises above 122 degrees (50° Centigrade); and it is precisely under such a temperature that many of the plants peculiar to the sandy and salt soil—as, for instance, the *Alhagi camelorum*—give to

[1] Petermann's *Mittheilungen*, &c., 1878, vol. xxiv. p. 293.

the desert a certain green appearance. In spring the hot days are followed by cold nights, so that the difference between the average temperature of day and night is enormous. In summer this difference is not so great, in consequence of the intense heat of the sand. Dew has never been observed. In the middle of September begin the long night frosts. In January the thermometer falls 36 degrees under zero Fahrenheit (−38 Centigrade), but there is little snow. In general, the climatic contrasts between the Turkestan deserts and the French Sahara are much stronger than the differences between their respective latitudes would lead one to expect. Thus, for instance, there are about 12 degrees difference between the latitude of Biskra and that of the Turkestan deserts, and still, at Biskra frost is almost unknown, the mean annual temperature being 70 degrees.

It is evident that, with such climatic discrepancies, the vegetation of the Turkestan deserts, compared with that of the Sahara, must offer great difference, but here also this difference is much stronger than it ought to be, taking particularly into account the high temperature of the Turkestan summers; and still, among the plants quoted in the above-mentioned paper, there is not a single species common to the Turkestan deserts and the Sahara. The flora of Kara-Kum seems to be so poor that, compared with that of the Sahara, the Algerian desert appears sometimes like a flourishing garden, particularly if we consider, not the large barren portions of the central and western Sahara, but the region situated near the northern boundary of the French Sahara, as among others, between Biskra and the oasis of Sidi-Okba and Zadja, where I was struck by the variety and beauty of very peculiar plants which, like brilliant jewels, glitter in the midst of the sea of sand.[1]

Now, if from the Turkestan deserts we direct our steps to the east, we reach the long chain of mountains which separate Siberia from Central Asia, a chain composed of the mountain groups collectively called Altaï, Sayan, and Jablonovoï, the two first of which I have visited, but without crossing them, in order to descend into the desert of Gobi. This immense desert—the largest in the world after the Sahara—begins almost immediately at the southern foot of the just-mentioned Siberian mountain range, and extends to the south to the chain of Kuenlun and its eastern ramifications, having from north to south about 1,800 miles, and about 4,000 miles from east to west—viz., from the mountainous chain of Changan to the country of Yarkand. The geographical position of the Gobi desert is, in the average, between the 35th and 45th degrees of northern latitude, and consequently almost under the latitude of Italy—a fact rendering still more remarkable the climate of the desert, which exemplifies in a most extraordinary way, and even more than in the Turkestan deserts, the influence of *eastern* longitudes, combined with the powerful radiation of large, more or less flat, surfaces; for, though under the latitude of Italy, but about 40 degrees more to the *east*, the Gobi offers the strongest contrasts between the seasons: the summer reminding one of tropical heat, and the winter of the cold of the polar regions, and that not only on account of its intensity, but also its duration—a fact of which Colonel Prejevalsky gives us the following striking example:—In the mountainous tract of Gansu, at a height of not much more than 3,000 feet, on May 16, the thermometer indicated 25 degrees (−4° Centigrade), and on May 28, the snow falling copiously formed on the soil a coating 5½ inches (16 centi-

[1] I have given an account of this curious desert flora in my last work upon Algeria, pp. 299–300, and 303–306.

mètres) thick, and the thermometer sunk to 22·46 degrees (−5·3 Centigrade). Now, this winter manifestation occurred under the latitude of 38 degrees (consequently under that of Palermo), and what is equally very peculiar is, that it did not cause great harm to the vegetation, for the Colonel gathered at this very time 76 plants—a curious example of the elasticity which certain plants possess of accommodating themselves to such extremes of temperature.

As the distinguished Russian traveller has seen of the Gobi desert more than any of his predecessors, I beg leave to quote his own words, which give a graphic portrait of the desert[1]: 'The general impression produced by the Gobi on the traveller has something gloomy and oppressive. During whole weeks the eyes repose on the same objects: unlimited yellow-coloured plains, furrowed rocks or steep hills, on the top of which one perceives sometimes the flying form of the antelope (*Antilope gutturosa*). The heavily laden camels cross, with measured solemn steps, hundreds and hundreds of miles, and still the desert does not change, keeping always its stern and monotonous appearance. The sun sets, the dark shadows of the night fall, the cloudless sky lights its million of stars, and the caravan stops. Happy to get rid of their loads, the camels lie down around the tents, and their drivers are occupied in preparing a frugal meal. One hour more, and men and animals are soundly asleep, and all around reigns the deathlike silence of the desert, as if no living creature were present. Across the whole of Gobi, from Urga (near the Siberian frontier) to Kalgan (near the frontier of China), there are, except the great post road maintained by the Mongols, several other caravan roads which are usually followed by the caravans carrying tea. Along the post road are stations erected at certain distances, the total number of which amounts to 47; and each of these is provided with a well and with a certain number of Mongol tents (*Yurt*), which represent our post-houses.'

This long post-road between Urga, Kalgan, and Peking was, during a long time, the only way by which travellers used to cross the Gobi in its whole breadth from north to south. But in the numerous publications of those travels, nothing is mentioned except the immense sand-accumulation, without the least hint in reference to the solid rocks on which those sands repose, or to any organic remains. In fact, it seems really that this monotonous road does not offer any interest whatever, for even the sharp-sighted Colonel Prejevalsky was not able to detect there anything of scientific importance; all he says of the country between Urga and the frontier of China is, that the soil of the Gobi consists of reddish, coarse-grained sand and pebbles belonging to different rocks. Fortunately, when, after concluding his extensive travels, the Colonel returned to Russia, he did not follow the trodden road from Peking to Urga, but took a much more westerly one, so that he crossed the desert in a direction in which it has never been visited previously, viz., from the mountains of Alashan to Urga. He describes this part of the desert as having a very undulated surface, and at certain points intersected by considerable heights composed chiefly of porphyry. In a depression he observed gneiss cropping out through the superficial deposits, and here and there this rock rising like little islands amidst the sea of sand.

Such denudations of the substratum are of the greatest importance to our knowledge of the solid framework of the desert; for if we could

[1] Col. N. Prejevalsky, *Reisen in der Mongolei*, from the Russian, by Albin Kohn, 2nd edit., p. 15.

ascertain that the rocks cropping out through the sand do not differ geologically from those which compose the border mountains of the desert, we should be induced to conclude that the one is merely a continuation of the other. Therefore let us throw a glance on the mountains which form the boundaries of the desert, beginning with the northern or Siberian side.

Here, I have been able myself to ascertain the Palæozoic age of the Altaï and the Sayan ranges,[1] consisting chiefly of clay-slate, limestone, porphyry, &c., and it is probable that the Jablonovoï chain, which is an eastern continuation of the Sayan, belongs equally to the same age.

The latest explorations of the Thian-Shan, or celestial range, the various ramifications of which form the southern and western boundary of the Gobi, tend also to prove that they are referable to an old geological formation. Colonel Prejevalsky, who more than once crossed the mountains of the south-eastern part of this boundary, mentions as the chief rocks composing them, granite, syenite, granulite, porphyry, diorite, mica-schist, clay-slate (*Thonschiefer*), chloritic schist and coal deposits. These are the geological elements which, according to Colonel Prejevalsky, constitute many of the marginal mountain ranges which he visited between Kalgan and the lake Kuku-Nor. He mentions very extensive coal-deposits in the mountains of Alashan, rising beyond 10,000 feet, as well as in the mountains, which in Northern Tibet form the eastern boundary of the Kuku-Nor. Those facts prove that the mountain range, representing the south-eastern boundary of the Gobi (from Kalgan to the Kuku-Nor) are composed of rocks which very likely belong to ancient geological formations.

A similar conclusion may be equally applied, with great probability, to the long chain of Chingan, which can be considered as the eastern boundary of the Gobi, and separates Mongolia from Manchuria; for this chan is intimately connected with the mountains of Inshan, one of the south-eastern marginal mountains of the Gobi, which Colonel Prejevalsky found composed of granite. At all events, all those mountains may be considered as the eastern extremity of the long chain of Kuenlun, which, according to Baron von Richthofen, is the largest and altogether the oldest mountain-chain of whole Asia.

We have, consequently, no lack of arguments in favour of a very ancient formation of the Gobi, and we can admit that at the time when the mountains which surround the desert were upraised, the immense space included in the interior precinct remained much lower, but still sufficiently high to form one of the loftiest table-lands of the world, the average height of which, Colonel Prejevalsky estimates to be near 4,000 feet (1285 mètres), with local depressions sinking to about 3,000 feet.

It is, therefore, probable that after its upheaval, this large surface has never been covered by the sea, as little as the Sahara-Lybian desert since the cretaceous and tertiary periods, or the Turkestan deserts since the Palæozoic epoch. Once more, in the Gobi, as in the other two deserts, the sand-accumulations had nothing to do with marine deposits; they were chiefly produced by atmospheric agencies, and as far as the Gobi is concerned, the frequent siliceous rocks, as granite, syenite, gneiss, &c., were particularly apt to yield sufficient materials to the formation of quartz sands.

[1] Tchihatchef, *Voyage scientifique dans l'Altaï oriental et les parties adjacentes de la frontière de Chine.* Paris: 1845.

After all I have said, it is superfluous to add that the upheaval of those deserts did not take place at once, but successively, as we have seen in the Sahara-Lybian desert, where the cretaceous and tertiary rocks appeared, one after the other, leaving still large tracts occupied by sea- or fresh-water basins, which were filled up only during the quaternary epoch, or even in a more recent one. Therefore, it is highly probable, that like the Sahara-Lybian desert, the Asiatic deserts were also crossed, long after the upheaval of their chief portions, by gulfs, or contained numerous fresh-water basins—a supposition which, in reference to the Gobi, is supported by the interesting considerations of E. Regel, on the character of the flora of Central Asia.[1] The learned director of the Botanical Garden of St. Petersburg, says: 'The salt steppes and sand deserts of the lower regions of Central Asia suggest the conclusion that, even at the beginning of the present epoch, consequently during the diluvial period, Central Asia was covered by a large fresh-water lake, through which the mountains rose as so many islands, until the time when the waters cut their way through the mountains, and were conveyed to the sea by the river Obi and perhaps the Amur, having left behind them large dry salt and sand steppes, which contain now an uniform flora, composed of halophytes and palustrian species, a flora which has probably opposed serious impediments to the migration of plants. As a striking exemplification of this fact we may quote the entire absence in Central Asia of any rhododendron and of any lily, whereas both these are copiously represented on the Caucasus, the Altaï, in the Baïkalian and Dahurian regions, on the northern declivities of the Tibetan Alps, and particularly in the Himalayan system. On the contrary, Central Asia appears a real vegetable centre for the genera *Tulipa*, *Allium*, *Eremurus*, *Elymus*, &c., and particularly for the family of *Salsolaceæ*.'

The still unknown part of the Gobi desert belonging to the most important regions of Central Asia, is so large, that all geographers and natural philosophers must hail with joy any undertaking capable of unveiling this *terra incognita*, particularly the mysterious western portion of it, containing the extensive lake Lob (Lob-Nor), which receives so many considerable rivers, like the Ak-su, Yarkand, Kashgar, and Kothan rivers. The intrepid traveller, who recently explored for the first time the Kuku-Nor lake, is certainly entitled, more than anybody else, to add to his important discoveries this new revelation of Central Asia.

The name of Colonel Prejevalsky is sufficiently known to all geographers; but what is perhaps not generally known and what enhances greatly the merit of this distinguished man, is the fact, that one of the most remarkable explorations of modern times has been carried out, with means the smallness of which would appear quite fabulous, had he not himself mentioned them. Now, Colonel Prejevalsky informs us,[2] that the whole amount of money he received from the Russian Government in order to meet all the expenses of three years of exploration in unknown and barbarous countries, was only 9,500 roubles, or about 1,100*l*. With this scanty support he crossed (from November 17, 1870, to September 19, 1873) nearly 18,000 miles, of which he mapped almost 9,000 miles.

But how could he, under such conditions, perform such a task,

[1] Petermann's *Mittheilungen*, 1882, vol. xxviii. p. 65.
[2] *Loc. cit.* p. 80.

tantulo tantum? Well, that he explains candidly himself; the revelation is so curious that it deserves to be quoted in his own words.[1] 'I had no means to take with me more than two Cossacks, and therefore my companion (Lieutenant Pylzow) and I, we were obliged to load and unload the camels ourselves, to take care of them, to gather fuel, &c.; in one word, to perform all the business of hard-working men. Neither could I engage a Mongolian interpreter, and my Cossack was altogether my interpreter, my workman, my shepherd and cook. Finally, our beggarly misery (*sic*) exposed us frequently to hunger whenever our gun did not procure us a dinner. After our return to Peking, I was much amused to hear one of the foreign ambassadors ask, how I was able to carry with me the bulk of Chinese metallic money, foreign money not being accepted by the Mongols. What would the honourable diplomatist think, had he known that at my starting from Peking I had with me no more than 230 Chinese lan, or 55*l*. 4*s*.'

But our astonishment increases still more when we learn that the energetic appearance of these *four* men, supported by their revolvers and breechloaders, never seen before in those countries, produced such a deep sensation and such a terror among the Mongols, that they considered them at least as supernatural creatures, having unlimited power, and being invincible by numbers. This kind of worship went so far that when Prejevalsky entered the town Dulan-kit, crowds of people ran to see what they called the famous *Chybilgan* (holy man) and all knelt at his passage.[2] Thus the poor Colonel, instead of being insulted as a helpless foreigner and checked in his progress, was greeted as a divine, irresistible magician, to whom everybody had to submit.

We cannot refuse our deepest admiration to a man, who, almost single-handed, explored, during three years, unknown countries, among fanatic and predatory populations, and brought back with him enormous collections, of which he gives us an enumeration,[3] without spending much more than 1,000*l*.

At all events let us hope that such travellers may be found in the future, for then we may be sure that the still unknown regions of our globe will be rapidly discovered, and that such noble victories may at last replace the bloodstained conquests of ambitious warriors.

[1] *Loc. cit.* p. 80. [2] *Loc. cit.* p. 381.

[3] According to his own statement, the collections which Colonel Prejevalsky brought to St. Petersburg, and which were transmitted to the Imperial Academy of Sciences, in order to be worked out, consisted of 238 species of birds, represented by 1,000 specimens, 70 specimens of mammals and amphibians, 11 species of fishes, more than 3,000 specimens of insects, 500–600 species of plants in 4,000 specimens, and a collection of rocks and minerals.

State of Crime in England, Scotland, and Ireland in 1880.

By Professor LEONE LEVI, *F.S.A.*

[A communication ordered by the General Committee to be printed *in extenso* among the Reports.]

[PLATE IV.]

§ 1. *Introductory.*

SELDOM has public attention been so intensely directed to the state of crime as within recent years, the frequent reports of appalling murders and other heavy offences, especially in Ireland, seeming to indicate that national morals are not improving as one might expect. Is it, or is it not, the fact that the spread of instruction and science is a safeguard against crime, and that all the forces of civilisation tend to refine and elevate the manners of the people? Happily a question of such momentous importance is capable of being tested by numbers, and it is given to the statistician to confirm or correct any hasty impression by the unanswerable logic of facts.

The statistical method, however, is not free from difficulty. We may gauge the criminality of a state by the enormity of the crimes therein committed at any given time, by their number and frequency, by the number of persons concerned in them, by the difficulty of detection, by the shelter and support afforded to criminals, by the tone of the public press with regard to crimes and criminals, or by the general character of the circumstances connected with their occurrence. What, however, if the crimes recorded should be altogether of a special character, the result, it may be of a political revolution, or of war, famine, or agrarian grievances? In times of great aberration, as in France during the Reign of Terror in 1791, or during the Commune in 1870, in Ireland in 1798 and 1821, events occur and crimes are committed, which cannot be taken as representing in any wise the ordinary criminality of the nation. At such times the moral sense of large numbers seems corrupted and blunted, passion and the lowest instincts appear to acquire complete sovereignty over reason and conscience, and public sentiment is, for the nonce, altogether in abeyance. There are, in truth, storms in the moral, as well as in the physical, atmosphere, the results of which, however startling, do not represent the ordinary state of morals, nor materially disturb the normal progress of society.

To arrive at any solid conclusions from statistical observation, the phenomena observed must embrace large numbers of facts, occurring over a lengthened period of time, and operating under widely different circumstances. Nor can we take the records of crime in any country as a complete or sufficient evidence of the morals of the nation, for the more efficient are the means for the detection of crime, the stronger the evidence that the moral sense of the nation rebels against it. Moreover, the moral nature of an act is, unfortunately, of no value in determining whether it is criminal or not; for, on the one hand, an act may be grossly immoral and yet it may not bring its agent within the pale of the criminal law, as in the case of adultery. And, on the other hand, an act perfectly innocent from a moral point of view, may render the doer amenable to punishment as a criminal.

The statistics of crime have often given rise to the theory, that a propensity for crime is within us, and that in committing it the criminal only follows a necessity of nature—that free will is, in fact, powerless, where a necessity, or fatality, really governs all our actions. Whence is it, it is asked, that nearly the same proportion of crimes are committed every year in proportion to population, and these in nearly the same proportion as against the person and against property? Buckle, in his 'History of Civilisation in England,' said that free will is only a dream of weak minds who obstinately refuse to admit that the world is held together by an inexorable law of causality. Quetelet saw in man a being subject to the action of certain laws which are beyond his power to control, knowing what is in him, yet conscious of responsibility for what he is doing. Wagner[1] represented the law of necessity which masters human actions as acting to such an extent that whatever happens occurs independently of the human will, and simply as a consequence of an absolute law. It is true, indeed, that human society is bound together by a thousand threads, and that every individual is affected by events which influence his conduct from his very birth; but human actions do not exhibit that same identity of character from age to age as the presence of such a law would necessitate. The operative causes of crime are, moreover, not always the same, and they act more powerfully on the weak than on the strong. Most certainly we are free to master them, and are even able to do so, if only by patience and endurance we acquire moral strength to conquer, instead of being conquered by them.

§ 2. *Judicial Statistics.*

The record of crime in the United Kingdom is embodied in the three annual volumes of Judicial Statistics for England and Wales, Scotland, and Ireland, respectively; those for England and Wales dating from 1856; for Scotland, from 1868; and from Ireland, from 1863. All the three fall considerably short of the plan, which I laid down in my paper on 'Judicial Statistics,' read before the Law Amendment Society, in 1855, as the result of the recommendation of the International Statistical Congress,[2] in that they do not furnish the necessary particulars regarding criminals in relation to the crimes committed. The Judicial Statistics for Ireland have recently omitted a most valuable part, consisting of the number of persons committed for trial in each county, for the use of which in this paper I am indebted to the Irish Office in London. And the Judicial Statistics of Scotland do not sufficiently distinguish indictable crimes from police offences, while differences of method and nomenclature render any comparison more difficult. Nevertheless, in these documents we have ample materials for determining the amount and progress of crime in the United Kingdom, and it is from them that all the facts commented upon in this paper are derived.

[1] A. Wagner: 'Ge[illegible]ssigkeit in den scheinbar willkürlichen Handlungen. Hamburg, 1864.' Drobiscn: 'Die moralische statistik und die menschliche Villensfreiheit, Leipsig, 1867.' *Annali di Statistica*, Serie 2, vol. xxiii. 1881.

[2] See Professor Levi's letter to Mr. Fonblanque, House of Lords paper, 541 of 1856, and Resolutions proposed by Lord Brougham in the House of Lords and Bill for the collection of judicial statistics, introduced by Lord Brougham and prepared by Professor Levi, March 3, 1856.

§ 3. *Population and Means of Repression.*

In order to appreciate the real value of the number of crimes and criminals annually reported, we must first take into account the population and number of police employed for the repression of crime, which were as follows :—

	England and Wales			Scotland			Ireland		
	Population	Police	Per 1,000	Population	Police	Per 1,000	Population	Police	Per 1,000
1871	22,760,000	27,425	1·20	3,366,000	3,003	0·89	5,387,000	14,028	2·60
1872	23,068,000	27,999	1·21	3,399,000	2,980	0·87	5,369,000	12,868	2·39
1873	23,356,000	28,550	1·22	3,430,000	3,029	0·88	5,337,000	12,957	2·42
1874	23,648,000	28,870	1·22	3,463,000	3,007	0·86	5,315,000	12,545	2·36
1875	23,944,000	29,460	1·23	3,495,000	3,075	0·88	5,309,000	12,352	2·32
1876	24,244,000	29,719	1·22	3,528,000	3,169	0·89	5,322,000	12,368	2·32
1877	24,547,000	30,016	1·22	3,561,000	3,241	0·91	5,339,000	12,456	2·33
1878	24,854,000	30,673	1·23	3,594,000	3,370	0·93	5,351,000	12,295	2·29
1879	25,165,000	31,047	1·23	3,627,000	3,446	0·95	5,362,000	12,397	2·31
1880	25,480,000	31,488	1·23	3,661,000	3,484	0·95	5,327,000	12,579	2·36

§ 4. *Number of Crimes committed.*

The first series of facts presented in the Judicial Statistics is the number of indictable crimes reported to the police, which may be assumed to represent the bulk, at least, of those committed; for though light offences may escape the vigilance of the police, or may never be brought to their cognisance, the heavier crimes are sure to be. According to these statistics, the number of indictable offences within the last ten years in England and Wales, and Ireland, was as follows :—

Years	England and Wales	Per 1,000	Ireland	Per 1,000
1871	45,149	1·97	8,155	1·51
1872	44,191	1·92	7,716	1·42
1873	45,214	1·92	6,942	1·31
1874	47,824	2·00	6,662	1·25
1875	47,045	1·96	6,598	1·24
1876	49,320	2·03	6,261	1·18
1877	50,843	2·07	6,328	1·19
1878	54,065	2·17	6,959	1·31
1879	52,447	2·04	8,089	1·49
1880	52,427	2·05	8,607	1·62
Average 1871–80	48,853	2·01	7,232	1·34

These figures indicate a slight increase of crime in recent years, both absolutely and relatively to population. It will be seen, however, that the number of crimes reported to have been committed is uniformly smaller in Ireland than in England and Wales, a very different result than is commonly imagined. The increase in the number of crimes at the commencement and end of the ten years is clearly due to the unhappy relations between landlords and tenants.

The number of crimes reported in England and Wales within the last twenty-five years, was as follows:—

Average	Number	Per 1,000
1857–61	53,674	2·72
1862–66	51,658	2·47
1867–71	54,036	2·43
1872–76	46,718	1·97
1877–81	52,195	2·07
Average of twenty-five years	51,656	2·33

§ 5. *Prosperity and Crime.*

The ten years, 1871–80, include five years of great prosperity of trade and high wages, and five years of decline of trade and lower wages. The value of exports of British produce and manufacture, and number of marriages, were as follows:—

Exports of British Produce and Manufacture, and Number of Marriages.

Good years		Number of Marriages per 1,000	Bad years		Number of Marriages per 1,000
	£			£	
1871	223,066,000	22·6	1876	200,639,000	20·9
1872	256,257,000	21·3	1877	198,893,000	20·3
1873	255,164,000	21·0	1878	192,849,000	21·6
1874	239,558,000	22·2	1879	191,532,000	20·7
1875	223,466,000	22·7	1880	223,060,000	20·5
Average	239,400,000	21·9	Average	201,200,000	20·8

And parallel to this we find the average number of crimes in the respective groups of five years to have been as follows:—

Number of Crimes Committed.

Years	England and Wales Per 1,000	Ireland Per 1,000
1871–75	1·98	1·36
1876–80	2·09	1·37

Indictable crimes are thus shown to have been greater in number during the five bad years than during the five good years.

§ 6. *Apprehensions for Crime.*

But the knowledge on the part of the police that an offence has been committed is no guarantee for the apprehension of the criminal. How often, on the contrary, does he escape from the pursuit of justice; in how many cases the highest reward fails to bring the criminal within the grasp of the law. The judicial statistics record the number of crimes committed, and the number of persons committed for trial, but no trace is given of the number of criminals who escape. That no crime shall remain unpunished, that the fugitive from justice shall be arrested and made amenable to law, that the sheltering of the criminal shall be regarded as a crime against public safety, these must ever be the aim and purpose of criminal jurisprudence. Filangieri, in his 'Scienza della Legislazione,' justly said, 'Neither the Royal Palace, nor the Temple, nor the Altar,

should be allowed to offer an asylum to one who violates the law. The majesty of the throne, the sacredness of the temple and of the altar are exalted, not lowered, by the triumph of justice.' The proportion of crimes to persons apprehended in England and Wales and Ireland was as follows:

England and Wales.

	Number of Crimes	Number of Apprehensions	Crimes to Persons
1880	52,427	22,231	2·35
Ireland.			
1880	8,607	5,409	1·59

Evidently, therefore, a larger number of crimes remains undetected in England and Wales than in Ireland, a fact which few would have anticipated. It should be remembered, however, that in many cases the same offender commits more than one crime, and that cases occur where the crime reported was not, in fact, committed.

During the last twenty-five years the proportion of persons apprehended to the number of crimes committed in England and Wales has been as follows:—

Years	No. of crimes	No. of persons apprehended	Per cent. of crimes to persons apprehended
1857–61	53,674	28,436	1·88
1862–66	51,658	28,920	1·78
1867–71	54,036	27,494	1·96
1872–76	46,036	22,452	2·05
1877–81	52,195	20,989	2·48
25 years' average	51,519	25,658	2·00

§ 7. *Number of Committals for Indictable Offences.*

Although during the last ten years there has been some slight increase of crime, the number of persons committed for trial has diminished in every part of the United Kingdom, as follows:—

Years	England and Wales		Scotland		Ireland		United Kingdom	
	Number	Per 1,000 persons	Number	Per 1,000 persons	Number	Per 1,000 persons	Number	Per 1,000 persons
1871	16,269	0·71	2,948	0·79	4,485	0·83	23,702	0·75
1872	14,801	0·64	3,044	0·89	4,476	0·82	22,321	0·70
1873	14,893	0·63	2,755	0·81	4,544	0·85	22,192	0·69
1874	15,195	0·64	2,880	0·82	4,130	0·77	22,205	0·68
1875	14,714	0·61	2,872	0·82	4,248	0·80	21,834	0·67
1876	16,078	0·66	2,716	0·77	4,146	0·78	22,940	0·69
1877	15,890	0·64	2,684	0·74	3,870	0·73	22,244	0·66
1878	16,372	0·65	2,922	0·81	4,183	0·77	23,477	0·69
1879	16,388	0·65	2,700	0·75	4,363	0·80	23,451	0·68
1880	14,770	0·58	2,583	0·69	4,716	0·89	22,069	0·63

The decrease in the number of committals has steadily continued for the last forty years, partly from a decided diminution of the heavier crimes, but partly also from the fact, that many offences previously tried by Sessions, are now disposed of summarily by magistrates.[1] The number of committals and proportion to population were as follows :—

Years	England and Wales		Scotland		Ireland	
	Average Number of Committals	Per 1,000	Average Number of Committals	Per 1,000	Average Number of Committals	Per 1,000
1841–50	27,842	1·65	4,091	1·46	25,978	3·24
1851–60	22,809	1·21	3,750	1·25	11,017	1·83
1861–70	19,307	0·82	3,284	1·03	5,017	0·82
1871–80	15,537	0·64	2,810	0·80	4,316	0·51

It will be observed that the proportionate number of committals is greatest in Scotland and least in Ireland, but throughout the period the diminution is considerable and satisfactory. Whence, however, is it, that with fewer crimes committed in Ireland than in England and Wales, the number of committals in proportion to population is generally larger in Ireland than in England and Wales? This is due partly to the larger number of apprehensions in proportion to crimes, the result to some extent of a larger police force, and partly to the greater vigour exercised by the magistracy in Ireland. The proportion of committals for indictable offences has been hitherto taken as a gauge for measuring the state and progress of crime in any country, yet, where possible, it is safer to measure the same by the number of crimes reported to have been committed.

Within the last twenty-five years the proportion committed for trial in England and Wales has been as follows :—

Years	Average numbers	Proportion per 1,000
1857–61	17,824	0·89
1862–66	19,757	0·97
1867–71	18,445	0·83
1872–76	15,136	0·64
1877–81	15,640	0·62
Twenty-five years' average	17,360	0·78

§ 8. *Committals and Convictions.*

The great test, however, of the existence of harmony between law and public opinion is the result of the trial, indicating as it does the greater

[1] By the Juvenile Offenders Acts, 10 & 11 Vict. c. 82, 13 & 14 Vict. c. 37, and 34 & 35 Vict. c. 78; and the Criminal Justice Acts, 18 & 19 Vict. c. 126, and 31 & 32 Vict. c. 116; simple larceny, the offender consenting, and not exceeding 16, and even above that age, the offender pleading guilty; stealing from the person, the offender pleading guilty, without reference to age or value; larceny as a clerk or servant, the offender pleading guilty, without reference to age or value; and even embezzlement by a clerk or servant, the offender pleading guilty, and the amount above 5*s*., or offender consenting, and amount not exceeding 5*s*.; all offences previously tried by sessions have been subjected to summary jurisdiction.

or less facility of procuring evidence. The following table seems to prove the weak point in the administration of justice in Ireland :—

Years	England and Wales			Scotland			Ireland		
	Committed	Convicted	Per cent.	Committed	Convicted	Per cent.	Committed	Convicted	Per cent.
1871	16,269	13,946	73	2,948	2,184	75	4,485	2,257	50
1872	14,801	10,862	73	3,044	2,259	75	4,276	2,565	57
1873	14,893	11,089	75	2,255	2,140	76	4,544	2,542	56
1874	15,195	11,509	75	2,880	2,231	77	4,130	2,367	57
1875	14,714	10,954	74	2,872	2,205	76	4,248	1,484	58
1876	16,078	12,195	74	2,716	2,051	75	4,146	2,346	56
1877	15,890	11,942	74	2,684	2,009	74	3,870	2,300	59
1878	16,372	12,473	75	2,922	2,273	76	4,183	2,293	54
1879	16,388	12,525	76	2,700	2,091	77	4,363	2,207	50
1880	14,770	11,214	75	2,583	2,046	79	4,716	2,383	50

On an average of ten years, 1871–80, the percentage of convictions was 78 per cent. in England and Wales, 76 per cent. in Scotland, and 55 per cent. in Ireland, the proportion in 1880 in Ireland having been only 50 per cent. The proportion of convictions in different classes of crime in Ireland is, moreover, very dissimilar, the proportion in cases of offences against property being considerably greater than in cases of offences against the person. In England, in 1880, 72 persons were apprehended for murder. Of these, 13 were discharged for want of evidence or want of prosecution, that being 18 per cent. of the whole, and 59 committed for trial, or 82 per cent. In Ireland, in the same year, 53 persons were apprehended for murder. And of these 37, or 69 per cent. of the whole, were discharged for want of evidence, and 16, or only 31 per cent., committed or bailed for trial. Of 61 committed for trial for murder in England, 28 were convicted, or 46 per cent. Of 35 committed for murder in Ireland, only 3 were convicted, or 8·5 per cent.

The Committee of the House of Lords on the operation of the Jury Laws in Ireland reported 'that the area in which trial by jury has broken down is not a small one, and that the social disorder, of which this is one of the numerous manifestations, is so deeply seated, that its rapid disappearance cannot be looked for.' Mr. Justice Lawson, in referring to the trial of agrarian cases before that Committee, stated that 'to send cases for trial, and to send the Judges round to try them, with a certainty of failure of justice, is not only a useless proceeding, but a great deal worse than useless, because it is the worst public manifestation of the impunity with which crime may be committed.' And it was in the spirit of the recommendation of that Committee that the Prevention of Crime (Ireland) Act, passed last session, entrusted the trial of certain agrarian offences to a Special Commission Court, with power to determine issues both of law and fact, special jurors being required in the case of indictable offences, with powers also, when deemed expedient, to change the venue to some county other than that in which the accused would otherwise be tried.

§ 9. *Summary Jurisdiction Offences.*

To obtain a full and complete view of the classes of crime most prevalent in the three United Kingdoms we must add to the statistics of

indictable offences those disposed of summarily by magistrates. The total number of persons thus tried in the last ten years was as follows:—

Years	England and Wales		Scotland		Ireland	
	Number	Per 1,000	Number	Per 1,000	Number	Per 1,000
1871	540,716	23·72	94,963	27·94	220,179	40·75
1872	559,929	24·34	101,070	29·70	211,470	39·14
1873	590,114	25·21	103,762	30·58	223,843	42·22
1874	622,174	26·35	109,872	31·42	228,501	43·11
1875	649,827	27·19	124,221	35·42	243,145	45·87
1876	661,613	27·35	120,817	34·56	256,312	48·30
·1877	653,053	25·60	120,809	33·61	266,298	50·24
1878	676,773	27·17	119,607	33·33	268,559	49·81
1879	641,038	25·43	104,468	28·88	255,670	54·81
1880	663,404	26·00	117,049	31·61	239,826	45·18

It thus appears that there has been a great increase in the number of persons brought before the magistrates for offences subject to summary jurisdiction. It should be observed, however, that in a large number of cases the same individuals come again and again before the Courts, that a large proportion of the cases so dealt with by magistrates consists of offences of a very light character, and that of late the number of offences involving imprisonment has been greatly increased.

During the last twenty-five years the number committed for summary jurisdiction in England and Wales has been as follows:—

Years	Average number of cases	Per 1,000 of population
1857–61	389,142	19·65
1862–66	442,493	21·79
1867–71	510,175	23·08
1872–76	616,751	26·13
1877–81	660,661	26·21
Twenty-five years' average	523,544	23·37

§ 10. *General Character of Crimes and Offences.*

Classified according to the general character of indictable and non-indictable offences, the following table indicates the relative criminality of England and Wales, Scotland, and Ireland, in 1880.

	England and Wales		Scotland		Ireland	
	Number	Per 1,000	Number	Per 1,000	Number	Per 1,000
Indictable offences committed for trial	14,770	0·58	2,583	0·69	4,716	0·89
Drunkenness	172,859	6·77	26,867	7·26	88,048	16·60
Lawlessness	490,545	19·24	90,182	24·37	151,778	28·63
Total	678,174	26·59	119,632	32·32	244,542	46·12

A good classification of crime would be a great aid in studying the working of our criminal jurisprudence. Generally crimes and offences may be divided into the following classes:—first, against public order

and justice; second, against morals; third, against the person; fourth, against property; fifth, against public decorum; and sixth, against local and other general statutes. Thus divided, the crimes and offences in the three kingdoms are as follows :—

Classes of Crimes and Offences	England and Wales		Scotland		Ireland	
	Number	Per 1,000	Number	Per 1,000	Number	Per 1,000
Against public order and justice	30,300	1·18	43,400	11·73	6,400	1·20
Against morals . . .	5,500	0·21	300	0·08	400	0·07
Against the person . .	72,400	2·83	19,100	5·16	35,300	6·66
Against property . .	95,400	3·74	18,100	5·02	13,000	2·45
Drunkenness . . .	172,900	6·78	26,900	7·27	88,000	16·60
Other offences . .	301,400	11·81	26,700	7·21	101,400	19·13
Total . . .	677,900	26·55	134,500	36·47	244,500	46·11

The comparison here instituted is doubtless far from exact. In the judicial statistics for England and Wales, the cases of assaults classed under offences against the person are distinguished from breaches of the peace, which appear under offences against public order. In the judicial statistics for Scotland, the cases of assault include breaches of the peace. Upon inquiry, however, it has been found, that of the total number of assaults reported in Scotland, about 21 per cent. may be considered as offences against the person, and the remainder simple breaches of the peace. In either case the classification is arbitrary. But taking them as they are, the facts are very suggestive. In proportion to population, the offences against public order are 11·73 to the 1,000 in Scotland, against 1·18 in England. The offences against morals, in the proportion of 0·21 to the 1,000 in England, against 0·07 per 1,000 in Ireland. The offences against the person in the proportion of 6·66 to the 1,000 in Ireland, against 2·83 in England; and the offences against property in the proportion of 5·02 per 1,000 in Scotland, against 1·45 in Ireland. Honour and property are safest in Ireland. The person is safest in Great Britain. But drunkenness is worst in Ireland, 16·60 per 1,000, against 6·78 in England, and 7·27 per 1,000 in Scotland.

§ 11. *Irish Crimes.*

What aggravates the state of crime in Ireland is the recurrence of social and political crimes and agrarian outrages, seldom indeed absent from Irish criminal jurisprudence, but, of late years, forming a large percentage of the crimes committed, and for which but few offenders are brought to justice. Nor are they light offences. At one time, these consisted of high treason, treasonable felony, administering treasonable oaths, using seditious language, having arms in a proclaimed district, attempting to seduce soldiers from their allegiance, and the like. At other times, as in recent years, they consisted in aggravated assaults, firing at the person, incendiary fires, and arson; killing, cutting, or maiming cattle; sending threatening letters, notices, or intimidations, and the like. Separate these from the ordinary crimes, and we find the proportion of crimes considerably less in Ireland than in England and Scotland.

§ 12. *Geography of Crime.*

If from a comparison of crimes and offences in the three kingdoms, we pass to an examination of the criminality of the several counties respectively, the field for study becomes wider and still more interesting. We may trace a diagram of indictable crimes in England from Cornwall, where there is the smallest number of committals, 0·21 per 1,000, to Hereford, where there is the largest number, 0·97 per 1,000; in Scotland, from Orkney to Bute, 0·12 to 3·05 per 1,000; in Ireland, from Wexford to Leitrim, 0·34 to 2·72 per 1,000. Lawlessness and drunkenness, however, follow other lines. If we take the counties in geographical order, the group of north midland and south-western counties have the least amount of crime, the north-western group the highest. Of the three Metropolitan counties, Middlesex and Dublin have a high degree of criminality. Not so Edinburgh. In lawlessness and drunkenness, however, Dublin and Edinburgh are much worse than Middlesex. Generally, the agricultural counties have less crime than the manufacturing and mineral counties. As a rule, crime follows closely the density of population. Cornwall, with only thirty-seven persons to the square mile, has less crime than Lancashire with 285 persons to the square mile. Great centres of population always contain a large number of restless, ill-conditioned men. They offer temptations, often irresistible, to wasteful luxury. They engender disease and want, and with physical and moral deterioration crime is nourished and fostered.

§ 13. *Race and Crime.*

Much might be learnt also of the relation of crime to races, if the population of the different counties were properly classified as Celts, Saxons, Scandinavian, &c. The large proportion of crimes and offences in places where the Irish are numerous indicates that nationality and race have considerable influence upon the nature and number of crimes. The Anthropometric Committee of the British Association have ascertained that the people of the north and north-eastern counties are taller and heavier than the people in the south and south-western counties, and the geography of crime shows precisely the opposite course. Putting the one against the other, we find that the taller the people the less is the crime, the shorter the people the more the crime. Nor is it a matter of surprise, for where the people are taller and better grown, the result of favourable conditions with respect to fresh air, exercise, and wholesome and sufficient food, there the amount of crime should be lower than wherever the people are small and stunted.

The nationality of prisoners during the last twenty-five years in England and Wales has been as follows:—

Per cent. of the whole number.

Years	English	Welsh	Scotch	Irish	Colonies	Foreign
1857–61	78·2	2·5	1·9	14·2	0·4	1·5
1862–66	78·0	2·7	1·9	14·8	0·4	1·3
1867–71	78·5	2·7	2·6	14·1	0·4	1·3
1872–76	77·8	2 7	2·3	14·5	0·4	1·4
1877–81	79·5	3·2	2·3	12·8	0·4	1·3
Average, 25 years .	78 4	2·7	2·2	14·0	0·4	1·3

§ 14. *Crime and Want.*

The motives of crime are not easily fathomed. A crime is often a symptom of moral disease, an evidence of total incapacity to control our grossest instincts. It is often associated with corporeal deformity, and may be the result of inherited propensities. But it is too often produced by circumstances connected with our social system. Some of the most operative causes of crime are certainly greed, cupidity, and want. The desire for acquisition is prominent in the English character. Wealth and comfort are sought after with much recklessness and disregard of consequences, whilst the sense of want is keen. Poverty, whether real or imaginary, affects the proper balance of the reason, suggests make-shifts, leads to temptation. The poor, living in squalid habitations, and surrounded by persons of low character, are easily brought to the very verge of criminality. Of whom consists the bulk of our criminals? Of persons having no occupation; of common labourers, whose means are precarious; of domestic servants, extravagant in their habits and utterly thriftless.

§ 15. *Crime and Thrift.*

Hence the relation of crime to savings and wealth is very intimate. The number of persons committed for trial in England and Wales in 1880 was 19 per cent. less than in Scotland, and 53 per cent. less than in Ireland. And so, in almost equal proportion, the amount of deposits at the Savings Banks Trustees and Post Office combined, in the same year, in England and Wales averaged 30 per cent. more than in Scotland, and 73 per cent. more than in Ireland. Take the twelve most criminal counties in England, and compare them with the twelve least criminal, and we find the latter having more in the savings banks and fewer paupers than the former have. Prosperity goes hand in hand with virtue; misery, with temptation and crime. Encourage thrift, promote the economic welfare of the masses, and you thereby operate the most effectively towards the repression of crime.

The graphic table which accompanies this paper, and Table C in the Appendix, exhibit the relation of crime to thrift in so far as it appears from the Savings Banks' returns, though the results are by no means uniform, especially from the fact that the amount in the savings banks is by no means the sole evidence of thrift.

A low rate of crime with a high rate of savings appears in the following counties:—

Counties	Committals per 1,000	Shillings per head in savings banks
Cornwall	0·21	59
Devon	0·27	85
Nottingham	0·33	56

A low rate of crime with a low rate of savings appears in

Durham	0·31	18
Westmoreland	0·33	25
Essex	0·36	17

A high rate of crime with a high rate of savings appears in

Hereford	0·97	70
Middlesex	0·93	83
Norfolk	0 53	59

§ 16. *Crime and Education.*

The bulk of criminals are generally found to be illiterate, and no wonder, for ignorance restricts the chances of employment, and renders a person the easy dupe of designing men. Education elevates the mind, raises the morals, enlarges the desire for the pure, and diminishes the desire for the impure, brings within the reach of all the works of the highest minds, and if it does not succeed in controlling the affections, it has an important influence in turning them to what is noble and right. Fear has been entertained that education may engender dissatisfaction with the lower occupations of life, and that by creating a capacity for greater enjoyments than the conditions of society enable the people to obtain, education may increase instead of diminishing the restiveness of the people, and thereby tend to the production of crime. But no such fear need be entertained, for the field of human labour is ever widening, and education offers resources and remedies which sweeten the acerbities of life and tend to ennoble the commonest of human services. Again, take the twelve most criminal counties in England and Wales, and you will find them to contain more persons not able to read and write than are to be found in the twelve least criminal counties.

§ 17. *Crime and Drunkenness.*

To what extent drunkenness proves to be the direct or indirect cause of crime is not easy to define. In the same manner as crime, drunkenness is often the effect of weak self-control, of want of moral power, though oftener still of wanton dissipation and sensuous indulgence. However produced, drunkenness unhinges the mind and is sure to be the concomitant of vice and crime. An inordinate expenditure in drink is, moreover, an immediate cause of much suffering and misery, and too often casts the labourer to the workhouse and the prison. Alas, how many hopes are blasted, how many families are ruined, through excess of drink. The twelve most criminal counties in England and Wales have a larger proportion of committals for drunkenness than the twelve least criminal counties. And the twelve counties where there is the largest number of cases of drunkenness, have likewise a larger proportionate number of committals for indictable offences, and nearly double the number of cases of lawlessness.

§ 18. *Crime and Family Quarrels.*

Where the causes are fathomed to their real source, family dissensions are found to contribute a pretty large quota of crime. Property, unrequited affections, unfaithfulness, and other quarrels, envenom the family life, and the results are an increasing number of divorces and judicial separations in the civil courts, and of suicides and crimes in the criminal. In France in 1879 15 per cent. of the crimes of poisoning, arson, murder, and assassination were ascribed to domestic dissensions and money disputes among relatives.

§ 19. *Crime and the Criminal Classes.*

There is yet another cause of crime ever active, ever present; th existence of the criminal classes, some at large, some in prison, som

adults, and some still young in age though old in malice. The judicial statistics give the number of these in England and Wales in 1880 at 70,338, or in the proportion of 2·77 per 1,000, and in Ireland at 8,991, or 1·69 per 1,000. The average number of prisoners during 1880 was in England 1·13 per 1,000; in Scotland 0·83 per 1,000; and in Ireland 0·62 per 1,000 of the population. Necessary and useful as a place of punishment, the prison is fatal to the character of the prisoner. The prison, alas, is a school, not of virtue, but of vice. Notwithstanding every effort to soften its asperities, to isolate the prisoner, and make him think, those who once enter the portals of the prison seldom, if ever, come out of it untainted and reformed. But what fatuity does it seem to make the prison the antechamber to the reformatory school. If the reformatory school is to spare the child from the contamination of the prison, why bring the child under an influence which will ever after haunt his mind and destroy his spirit and independence?

§ 20. *Crime in the United Kingdom and France.*

A comparison of the state of crime in the United Kingdom as a whole with France gives unsatisfactory results. In the United Kingdom, the total number of persons summarily disposed of by the magistrates, and committed for trial was, in 1880, 1,043,000, or in a proportion of 29·62 per 1,000. In France, the total number of persons before the Assizes, Correctional Tribunals, and Simple Police in 1879, was 636,000, or 17·18 per 1,000. The total number committed for trial in the United Kingdom for murder, attempt to murder, and manslaughter in 1880 was 808, or in the proportion of 0·023 per 1,000. In France, the total number before the Court of Assize for parricide, poisoning, assassination, infanticide, and murder in 1879, was 645, or 0·017 per 1,000. In the United Kingdom, the total number of cases of drunkenness in 1880 was 287,000, or 8·15 per 1,000; in France, the total number in 1879 was 63,000, or 1·70 per 1,000.

§ 21. *Criminal Reforms.*

The state of crime in the United Kingdom is not, I am sorry to say, as favourable as we should like it to be. Doubtless we may congratulate ourselves that, as compared with former years, there is a notable diminution of the heavier crimes, nevertheless the total number of crimes and offences is large, and they are the sure symptoms of a grievous disease in the body politic. What is to be done? Sanitary science or hygiene has done much to eradicate or modify physical disease. Jurisprudence and ethics must combine in the removal of those causes which contribute to crime. Large indeed is the field open for the moral and social reformer. In the improvement of the homes of the people, in the promotion of health and comfort, of education, temperance, and self-control among the masses, in the advancement of measures calculated to further solid progress, much effort is needed, much perseverance, much faith. Happily, large as is the field of labour, many are the labourers, who, by means both of repression and prevention, are seeking to remove those clouds which now obscure our moral horizon, and we need not fear but their labour will be crowned with success.

APPENDIX.

A Crimes and Offences in Counties in 1880.

England and Wales.

Counties	Population Census 1881	Number committed for Trial 1880	Per 1,000	Number of Cases of Lawlessness	Per 1,000	Number of Cases of Drunkenness	Per 1,000
Bedford	149,000	94	0·63	1,687	11·32	383	2·57
Berks	218,000	102	0·47	2,746	12·61	587	2·69
Bucks	176,000	86	0·49	2,251	12 77	353	2·00
Cambridge	185,000	58	0·31	1,951	11·53	273	1·47
Chester	643,000	412	0·64	12,805	19·91	4,720	7·34
Cornwall	329,000	70	0·21	2,096	6·37	537	1·63
Cumberland	251,000	134	0·53	4,035	16·08	2,344	9 33
Derby	461,000	149	0·32	8,878	19·23	2,876	6·26
Devon	604,000	167	0·27	7,036	11·65	2,134	3·53
Dorset	191,000	93	0·48	2,597	13·59	493	2·60
Durham	868,000	272	0·31	21,758	25·10	11,782	3·50
Essex	576,000	210	0·36	3,523	6·10	393	1·61
Gloucester	572,000	307	0 53	10,290	18·00	2,272	3·97
Hereford	121,000	118	0·97	2,633	21·78	608	5·00
Hertford	203,000	113	0 50	2,084	11·70	390	2·20
Huntingdon	60,000	16	0·26	791	13·19	103	1·72
Kent	978,000	401	0·41	7,554	8·43	1,780	1·84
Lancaster	3,454,000	2,995	0 86	93,098	27·03	46,241	13·29
Leicester	324,000	133	0·41	5,571	17·30	1,196	3 72
Lincoln	470,000	200	0·42	9,878	22·08	2,862	5·10
Middlesex	2,919,000	2,725	0 93	98,718	20·72	32,233	6·76
Monmouth	211,000	129	0·61	4,577	21·70	1,402	6·60
Norfolk	445,000	238	0·53	4,927	11 03	1,058	2 37
Northampton	273,000	144	0·56	3,226	11·80	796	2·90
Northumberland	434,000	149	0·34	9,864	22·70	7,033	16·20
Nottingham	392,000	130	0·33	8,815	22·42	2,150	5·50
Oxford	180,000	94	0 52	2,313	12·79	381	2·11
Rutland	21,000	7	0·33	249	11·85	46	2·19
Salop	248,000	128	0·52	4 170	16 81	1,809	7·20
Somerset	469,000	210	0·44	7,013	14·86	677	1·44
Southampton	593,000	305	0·51	7,743	13·08	1,941	3·27
Stafford	981,000	549	0·56	24,871	25·35	6,349	6·47
Suffolk	356,000	124	0·35	1,039	2·91	154	0·43
Surrey	1,436,000	816	0·56	2,254	11·93	611	3·23
Sussex	490,000	246	0·50	4,417	9·00	1,329	2·71
Warwick	737,000	503	0·68	16,000	21·72	3,600	4·88
Westmoreland	64,000	21	0·32	1,022	15·97	345	5·34
Wilts	259,000	110	0·42	2,603	10·05	350	1·35
Worcester	380,000	249	0·65	6,797	17·89	2,001	5·26
York	2,886,000	1,224	0·42	51,496	17·84	17,242	8·23
	24,608,000	14,221	0·59	465,534	19·31	164,639	6·82

England and Wales—continued.

Wales.

Counties	Population Census 1881	Number committed for Trial 1880	Per 1,000	Number of Cases of Lawlessness	Per 1,000	Number of Cases of Drunkenness	Per 1,000
Anglesea	51,000	17	0·33	789	15·47	262	5·13
Brecon	58,000	29	0·60	1,253	21·60	347	5·98
Cardigan	70,000	10	0·14	1,034	14·77	267	3·81
Carmarthen	125,000	35	0·28	1,942	15·53	559	4·47
Caernarvon	119,000	63	0·53	1,691	14·21	1,231	10·34
Denbigh	109,000	33	0·30	1,334	12·24	431	3·95
Flint	80,000	29	0·36	1,402	17·53	356	4·45
Glamorgan	512,000	241	0·45	11,725	22·96	3,945	7·70
Merioneth	55,000	20	0·36	569	10·35	217	3·94
Montgomery	66,000	50	0·76	1,053	15·94	260	3·93
Pembroke	92,000	15	0·16	1,867	20·29	322	3·50
Radnor	23,000	7	0·29	352	14·61	103	4·29
	1,360,000	549	0·37	25,011	17·86	8,300	5·92
	25,968,000	14,770	0·58	490,545	19·23	172,859	6·77

Scotland.

Counties	Population Census 1881	Number committed for Trial 1880	Per 1,000	Number of Cases of Lawlessness	Per 1,000	Number of Cases of Drunkenness	Per 1,000
Aberdeen	268,000	71	0·26	1,509	16·87	244	0·91
Argyll	76,000	105	1·38	1,061	13·96	112	1·47
Ayr	218,000	84	0·38	3,644	16·72	536	2·45
Banff	63,000	10	0·15	301	1·94	13	0 20
Berwick	35,000	22	0·60	368	10·52	32	0·91
Bute	18,000	57	3·05	78	4·33	—	—
Caithness	39,000	24	0·61	233	5·98	12	0·30
Clackmannan	26,000	19	0·73	897	34·47	83	3·20
Dumbarton	75,000	45	0·60	1,572	20·98	297	3·94
Dumfries	76,000	35	0·46	1,413	18·57	151	2·00
Edinburgh	389,000	255	0·65	9,905	25·47	3,505	9·00
Elgin	44,000	30	0 66	394	9·95	52	1·18
Fife	172,000	85	0·49	1,003	5·87	394	2·25
Forfar	266,000	165	0·62	4,589	17·26	23,51	8·83
Haddington	38,000	10	0·26	759	19·97	163	4·29
Inverness	90,000	96	1·06	769	8·54	82	0·91
Kincardine	34,000	9	0·26	185	5·44	7	—
Kinross	7,000	5	0·71	34	4·85	1	—
Kirkcudbright	42,000	21	0·50	233	5·64	4	—
Lanark	904,000	758	0·84	45,661	49·43	15,400	17·00
Linlithgow	43,000	51	1·19	957	22 26	177	4·11
Nairn	10,000	3	0·30	171	16·19	23	2·30
Orkney	32,000	4	0·12	—	—	—	—
Peebles	14,000	2	0·14	278	19·98	41	2·90
Perth	129,000	123	0·95	1,229	9·62	230	1·78
Renfrew	263,000	223	0·84	4,723	17·97	2,282	8·66
Ross & Cromarty	79,000	115	1·45	312	3·94	—	—
Roxburgh	53,000	32	0·60	1,396	16·34	149	2·81
Selkirk	26,000	16	0·61	1,013	38·96	70	2·69
Stirling	112,000	47	0·42	1,367	12·20	353	3·15
Sutherland	23,000	7	0·30	66	2·86	3	—
Wigtown	39,000	31	0·79	292	7·49	7	—
Zetland	30,000	23	0·77	—	—	—	—
	3,734,000	2,583	0·69	102,600	27·72	26,867	7·26

Ireland.

Counties	Population Census 1881	Number committed for Trial	Per 1,000	Number of Cases of Lawlessness	Per 1,000	Number of Cases of Drunkenness	Per 1,000
Antrim . .	423,000	175	0·42	2,796	6·62	2,479	5·85
Armagh . .	163,000	168	1·03	16,217	100·49	10,139	62·19
Carlow . .	47,000	56	1·19	1,850	39·11	1,742	37·10
Cavan . .	129,000	126	0·97	1,176	7·68	1,332	10·32
Clare . .	141,000	119	0·84	3,176	24·55	1,821	12·84
Cork . .	493,000	569	1·15	15,838	32·12	8,440	17·12
Donegal . .	205,000	123	0·60	2,573	12·56	1,519	7·40
Down . .	270,000	161	0·60	3,618	12·66	3,559	13·18
Dublin . .	418,000	739	1·72	42,072	100·65	10,992	26·29
Fermanagh .	84,000	46	0·54	1,082	16·76	1,211	14·21
Galway . .	242,000	284	1·17	6,850	28·00	4,117	17·00
Kerry . .	200,000	192	0 96	6,662	32·40	3,528	17·60
Kildare . .	76,000	58	0·76	2,276	29·97	1,814	23·85
Kilkenny . .	99,000	103	1·04	2,230	22·55	1,914	19·30
King's County .	73,000	78	1·07	1,997	27·65	1,233	16·89
Leitrim . .	90,000	245	2·72	1,614	14·97	1,203	13·33
Limerick . .	177,000	160	0·90	4,011	22·64	3,166	17·90
Londonderry .	165,000	121	0·73	3,068	18·56	2,922	17·70
Longford . .	61,000	100	1·17	1,194	17·06	1,249	20·47
Louth . .	78,000	49	0·63	2,379	22·22	1,439	18·44
Mayo . .	243,000	271	1·11	3,659	14·48	1,717	17·64
Meath . .	86,000	81	0·94	2,355	27·39	1,405	16·34
Monaghan .	103,000	76	0·73	1,818	17·66	2,062	20·00
Queen's County.	73,000	109	1·49	1,896	25·96	993	13·60
Roscommon .	132,000	94	0·71	2,953	22·37	1,398	10·59
Sligo . .	111,000	92	0·83	2,459	22·15	1,953	22·15
Tipperary . .	199,000	567	2·85	4,292	21·57	4,055	21·57
Tyrone . .	197,000	132	0·67	3,502	17·77	3,036	17·77
Waterford .	113,000	104	0·92	2,337	20·69	2,253	20·69
Westmeath .	72,000	26	0·36	1,962	27·21	1,507	27·21
Wexford . .	124,000	42	0·34	1,949	15·74	1,037	15·74
Wicklow . .	74,000	40	0·54	1,652	22·29	1,050	22·29
	5,160,000	4,716	0·90	151,778	29·18	88,048	16·93

B. Geography of Crime.

England and Wales.

Counties	Committals per 1,000	Summary Jurisdiction: Lawlessness per 1,000	Summary Jurisdiction: Drunkenness per 1,000
South Eastern:—			
Surrey	0·56	11·93	3·23
Kent	0·41	8·43	1·84
Sussex	0·50	9·00	2·71
Southampton . .	0·51	13·08	3·27
Berkshire. .	0·47	12·61	2·69
	0 49	11·01	2·74

England and Wales—continued.

Counties	Committals per 1,000	Summary Jurisdiction Lawlessness per 1,000	Summary Jurisdiction Drunkenness per 1,000
South Midland:—			
Middlesex	0·93	20·72	6·76
Hertford	0·50	11·70	2·20
Bucks	0·49	12·77	2·00
Oxford	0·52	12·79	2·11
Northampton	0·56	11·80	2·90
Huntingdon	0·26	13·19	1·72
Bedford	0·63	11·32	2·57
Cambridge	0·31	11·53	1·47
	0·52	13·43	2·69
Eastern Counties:—			
Essex	0·36	6·10	1·61
Suffolk	0·35	2·91	0·43
Norfolk	0·53	11·03	2·37
	0·41	6·68	1·47
South Western:—			
Wilts	0·42	10·05	1·35
Dorset	0·48	13·59	2·60
Devon	0·27	11·65	3·53
Cornwall	0·21	6·37	1·63
Somerset	0·44	14·86	1·44
	0·36	11·30	2·11
West Midland:—			
Gloucester	0·53	18·00	3·97
Hereford	0·97	21·78	5·00
Salop	0·52	16·81	7·20
Stafford	0·56	25·35	6·47
Worcester	0·65	17·89	5·26
Warwick	0·68	21·72	4·88
	0·65	20·26	5·15
North Midland:—			
Leicester	0·41	17·30	3·72
Rutland	0·33	11·85	2·19
Lincoln	0·42	22·08	5·10
Nottingham	0·33	22·42	5·50
Derby	0·32	19·23	6·26
	0·36	18·63	4·55
North Western:—			
Cheshire	0·64	19·91	7·34
Lancashire	0·86	27·03	13·29
	0·75	23·47	10·31
York	0·42	17·84	8·26
Northern:—			
Durham	0·31	25·10	3·50
Northumberland	0·34	22·70	16·20
Cumberland	0·53	16·08	9·33
Westmoreland	0·32	15·97	5·34
	0·37	19·97	8·76
Monmouth	0·61	21·70	6·60
South Wales	0·30	18·28	4·95
North Wales	0·44	14·32	5·29
	0·45	18·00	5·61

C. Comparison of Twelve of the Most Criminal Counties with Twelve of the Least Criminal Counties in England and Wales.

Most Criminal Counties.

Counties	Summary Jurisdiction: Committals per 1,000	Summary Jurisdiction: Lawlessness per 1,000	Summary Jurisdiction: Drunkenness per 1,000	Pauperism per 1,000	Savings Banks shillings deposit per head	Ignorance per cent. signing with marks mean of m. and f.	Density persons to acre	Height of Adult persons Inches
Hereford	0·97	21·78	5·00	65	70	14·9	22	66·45
Middlesex	0·93	20·72	6·76	40	83	10·0	161	66·69
Lancaster	0·86	27·03	13·29	44	43	20·7	285	67·49
Warwick	0·68	21·72	4·88	50	49	19·7	130	67·12
Worcester	0·65	17·89	5·26	47	44	18·8	44	67·22
Bedford	0·63	11·32	2·57	47	42	25·8	50	67·07
Monmouth	0·61	21·70	6·60	62	34	30·1	57	66·45
Cumberland	0·53	16·08	9·33	42	42	16·3	25	68·48
Gloucester	0·53	18·00	3·97	68	61	14·0	71	66·31
Norfolk	0·53	11·03	2·37	62	59	17·9	33	68·34
Northampton	0·56	11·80	2·90	53	44	14·5	43	67·26
Stafford	0·56	25·35	6·47	58	28	28	134	67·82
	0·68	18·70	5·78	54	50	19·2	88	67·22

Least Criminal Counties.

Counties	Summary Jurisdiction: Committals per 1,000	Summary Jurisdiction: Lawlessness per 1,000	Summary Jurisdiction: Drunkenness per 1,000	Pauperism per 1,000	Savings Banks shillings deposit per head	Ignorance per cent. signing with marks mean of m. and f.	Density persons to acre	Height of Adult persons Inches
Cornwall	0·21	6·37	1·63	56	59	19·7	37	67·94
Huntingdon	0·26	13·19	1·72	44	40	16·3	25	66·78
Durham	0·31	25·10	3·50	36	18	22·5	134	67·70
Cambridge	0·31	11·53	1·47	76	57	17·3	35	66·78
Devon	0·27	11·65	3·53	62	85	10·6	36	67·28
Derby	0·32	19·23	6·26	35	42	25·8	70	67·80
Nottingham	0·33	22·42	5·50	34	56	18·0	74	67·38
Rutland	0·33	11·85	2·19	43	29	9·4	22	67·29
Suffolk	0·35	2·91	0·43	56	51	18·9	37	67·95
Westmoreland	0·33	15·97	5·34	36	25	8·0	12	68·00
Northumberland	0·34	22·70	16·20	36	62	14·5	33	68·59
Essex	0·36	6·10	1·61	17	25	13·2	54	68·00
	0·32	14·08	4·11	47	65	16·1	47	67·62

D. Gradation of Criminality in English Counties.

	Crime	Per 1,000		Lawlessness	Per 1,000		Drunkenness	Per 1,000
1	Hereford	0·97	1	Lancaster	27·03	1	Northumberland	16·20
2	Middlesex	0·93	2	Stafford	25·35	2	Lancaster	13·29
3	Lancaster	0·86	3	Durham	25·10	3	Cumberland	9·33
4	Warwick	0·68	4	York	24·93	4	York	8·26
5	Worcester	0·65	5	Northumberland	22·70	5	Chester	7·34
6	Chester	0·64	6	Nottingham	22·42	6	Salop	7·20
7	Bedford	0·63	7	Lincoln	22·08	7	Middlesex	6·76
8	Monmouth	0·61	8	Hereford	21·78	8	Monmouth	6·60
9	Surrey	0·56	9	Warwick	21·72	9	Stafford	6·47
10	Northampton	0·56	10	Monmouth	21·70	10	Derby	6·26
11	Stafford	0·56	11	Middlesex	20·72	11	Nottingham	5·50
12	Cumberland	0·53	12	Chester	19·91	12	Westmoreland	5·34
13	Norfolk	0·53	13	Derby	19·23	13	Worcester	5·26
14	Gloucester	0·53	14	Gloucester	18·00	14	Lincoln	5·10
15	Oxford	0·52	15	Worcester	17·89	15	Hereford	5·00
16	Salop	0·52	16	Leicester	17·30	16	Warwick	4·88
17	Southampton	0·51	17	Salop	16·81	17	Gloucester	3·97
18	Hertford	0·50	18	Cumberland	16·08	18	Leicester	3·72
19	Sussex	0·50	19	Westmoreland	16·01	19	Devon	3·53
20	Bucks	0·49	20	Somerset	14·86	20	Durham	3·50
21	Dorset	0·48	21	Dorset	13·59	21	Southampton	3·27
22	Berks	0·47	22	Huntingdon	13·19	22	Surrey	3·23
23	Somerset	0·44	23	Southampton	13·08	23	Northampton	2·90
24	Lincoln	0·42	24	Oxford	12·19	24	Sussex	2·71
25	York	0·42	25	Bucks	12·77	25	Berks	2·69
26	Wilts	0·42	26	Berks	12·61	26	Dorset	2·60
27	Kent	0·41	27	Surrey	11·93	27	Bedford	2·57
28	Leicester	0·41	28	Rutland	11·85	28	Norfolk	2·37
29	Essex	0·36	29	Northampton	11·80	29	Hertford	2·20
30	Suffolk	0·35	30	Hertford	11·70	30	Rutland	2·19
31	Northumberland	0·34	31	Devon	11·65	31	Oxford	2·11
32	Rutland	0·33	32	Cambridge	11·53	32	Bucks	2·00
33	Nottingham	0·33	33	Bedford	11·31	33	Kent	1·84
34	Westmoreland	0·32	34	Norfolk	11·03	34	Huntingdon	1·72
35	Derby	0·32	35	Wilts	10·05	35	Cornwall	1·63
36	Durham	0·31	36	Sussex	9·00	36	Essex	1·61
37	Cambridge	0·31	37	Kent	8·43	37	Cambridge	1·47
38	Devon	0·27	38	Cornwall	6·37	38	Somerset	1·44
39	Huntingdon	0·26	39	Essex	6·10	39	Wilts	1·35
40	Cornwall	0·21	40	Suffolk	2·91	40	Suffolk	0·43

E. Crime in Relation to Occupation.

Agricultural Counties		Manufacturing, Industrial, and Mining Counties	
Counties	Committals per 1,000	Counties	Committals per 1,000
Bedford	0·63	Chester	0·64
Berks	0·47	Cornwall	0·21
Bucks	0·49	Derby	0·32
Cambridge	0·31	Durham	0·31
Cumberland	0·53	Gloucester	0·53
Devon	0·27	Kent	0·41
Dorset	0·48	Lancaster	0·86
Essex	0·36	Leicester	0·41
Hereford	0 97	Middlesex	0·93
Hertford	0·50	Monmouth	0·61
Hunts	0·26	Northumberland	0·34
Lincoln	0·42	Nottingham	0·33
Norfolk	0·53	Salop	0·52
Northampton	0·56	Stafford	0·56
Oxford	0 52	Surrey	0·56
Rutland	0·33	Warwick	0·68
Somerset	0·44	Worcester	0·65
Southampton	0·56	York	0·42
Sussex	0 50		
Westmoreland	0·32		
Wilts	0·42		
Suffolk	0·35		
Average	0·48	Average	0·51

F. Suicides.

England and Wales.

	Average number	Per 1,000,000
1857–61	1,309	66
1862–66	1,351	65
1867–71	1,489	67
1872–76	1,555	65
1877–81	1,826	72
Twenty-five years' average	1,361	67

G. Savings Banks.

Total Amount and Proportion per head of the Population in each County held at the Savings Banks in 1880.

England and Wales.

Counties	Post Office Savings Bank	Trustees Savings Banks	Total	Per head
	000 omitted	000 omitted	000 omitted	s.
Bedford	£187	£131	£318	42
Berks	386	518	904	83
Bucks	236	124	360	41
Cambridge	238	293	531	57
Cheshire	553	1,203	1,756	54
Cornwall	224	760	984	59
Cumberland	113	421	534	42
Derby	377	591	968	42
Devon	563	2,022	2,585	85
Dorset	265	299	564	59
Durham	465	340	805	18
Essex	882	361	1,243	25
Gloucester	820	943	1,763	61
Hampshire	1,237	347	1,584	53
Hereford	121	308	429	70
Hertford	445	88	533	52
Hunts	121	—	121	40
Kent	2,315	420	2,735	56
Lancaster	1,797	5,633	7,430	43
Leicester	274	426	700	43
Lincoln	424	865	1,289	55
Middlesex	6,727	5,408	12,135	83
Monmouth	249	113	362	34
Norfolk	595	721	1,316	59
Northampton	277	324	601	44
Northumberland	236	1,124	1,360	62
Nottingham	312	783	1,095	56
Oxford	328	329	657	62
Rutland	31	—	31	29
Salop	358	796	1,154	93
Somerset	523	900	1,423	60
Stafford	1,069	308	1,377	28
Suffolk	433	491	924	31
Surrey	2,726	603	3,329	49
Sussex	974	602	1,576	64
Warwick	1,565	256	1,821	49
Westmoreland	49	32	81	25
Wilts	295	464	759	58
Worcester	515	328	843	44
York	1,244	3,978	5,222	36
	30,546	33,652	64,198	52

England and Wales—continued.

Wales.

Counties.	Post Office Savings Bank	Trustees Savings Banks	Total	Per head
	000 omitted	000 omitted	000 omitted	s.
Anglesea	£37	—	£37	14
Brecon	48	£29	77	26
Cardigan	46	44	90	25
Carmarthen	88	104	192	30
Carnarvon	63	22	85	14
Denbigh	79	84	163	29
Flint	60	101	161	40
Glamorgan	330	372	702	27
Merioneth	33	—	33	12
Montgomery	49	109	158	48
Pembroke	86	193	279	60
Radnor	22	21	43	35
	941	1,079	2,020	29
	31,487	34,731	66,219	52

Scotland.

Counties.	Post Office Savings Bank	Trustees Savings Banks	Total	Per head
Aberdeen	46	433	479	36
Argyll	22	11	33	9
Ayr	54	—	54	5
Banff	11	23	34	11
Berwick	12	5	17	10
Bute	3	34	37	41
Caithness	5	32	37	19
Clackmannan	5	—	5	4
Dumbarton	14	19	33	9
Dumfries	16	16	32	8
Edinburgh	63	1,291	1,354	70
Fife	41	231	272	32
Forfar	38	535	573	43
Haddington	10	—	10	5
Inverness	14	71	85	19
Kincardine	5	90	95	56
Kinross	2	—	2	6
Kirkcudbright	10	18	28	13
Lanark	90	3,026	3,116	69
Linlithgow	12	—	12	6
Moray and Elgin	15	28	43	20
Nairn	2	12	14	28
Orkney	3	—	3	2
Peebles	3	—	3	4
Perth	25	155	180	28
Renfrew	20	185	205	14
Ross and Cromarty	15	7	22	6
Roxburgh	12	161	173	65
Selkirk	6	16	22	17
Shetland	5	—	5	3
Stirling	23	173	196	35
Sutherland	5	—	5	4
Wigtown	11	—	11	6
	620	6,574	7,194	38

Ireland.

Counties	Post Office Savings Bank	Trustees Savings Banks	Total	Per head
	000 omitted	000 omitted	000 omitted	s.
Antrim	£199	£217	£416	20
Armagh	29	180	209	25
Carlow	15	—	15	6
Cavan	21	10	31	5
Clare	19	17	36	5
Cork	127	405	532	22
Donegal	39	—	39	4
Down	85	81	166	12
Dublin	338	255	593	28
Fermanagh	17	156	173	41
Galway	55	—	55	5
Kerry	23	—	23	2
Kildare	31	17	48	13
Kilkenny	25	—	25	5
King's County	20	11	31	9
Leitrim	12	—	12	3
Limerick	36	98	134	15
Londonderry	34	315	349	42
Longford	9	—	9	3
Louth	52	11	63	16
Mayo	45	—	45	4
Meath	18	1	19	4
Monaghan	18	29	47	9
Queen's County	18	9	27	7
Roscommon	16	29	45	7
Sligo	28	—	28	5
Tipperary	62	19	81	8
Tyrone	46	126	172	17
Waterford	24	90	114	19
Westmeath	25	10	35	10
Wexford	38	9	47	7
Wicklow	32	5	37	10
	1,556	2,100	3,656	14

H. Gradation of Thrift in English Counties.

Savings Banks	Shillings per head	Savings Banks	Shillings per head
1 Salop	93	21 Hertford	52
2 Devon	85	22 Suffolk	51
3 Middlesex	83	23 Surrey	49
4 Berks	83	24 Warwick	49
5 Hertford	70	25 Worcester	44
6 Sussex	64	26 Northampton	44
7 Oxford	62	27 Lancaster	43
8 Northumberland	62	28 Leicester	43
9 Gloucester	61	29 Bedford	42
10 Somerset	60	30 Cumberland	42
11 Cornwall	59	31 Derby	42
12 Norfolk	59	32 Bucks	41
13 Dorset	59	33 Hunts	40
14 Wilts	58	34 York	36
15 Cambridge	57	35 Monmouth	34
16 Kent	56	36 Rutland	29
17 Nottingham	56	37 Stafford	28
18 Lincoln	55	38 Westmoreland	25
19 Chester	54	39 Essex	25
20 Southampton	53	40 Durham	18

On the Treatment of Steel for the Construction of Ordnance, and other purposes. By Sir WILLIAM ARMSTRONG, *C.B., F.R.S.*

[A communication ordered by the General Committee to be printed *in extenso* among the Reports.]

THE improvement which of late years has been effected in the manufacture of steel, and the control which has been attained over the quality produced, now seem to justify its exclusive employment in the construction of ordnance. We have, therefore, to consider what are the conditions under which it can be most favourably used for that and other purposes.

There is at present much want of a proper definition of steel. The term was formerly confined to iron containing a much higher proportion of combined carbon than is to be found in the so-called mild steels of the present day. Where steel *ends* in the downward scale of carbonisation, and where iron *begins*, it is impossible to say, for not even wrought iron is absolutely free from carbon. The chief distinction between iron and steel now seems to lie in the process of manufacture—steel being operated upon in a state of fusion, while iron is dealt with in a state of agglutination. But, even in the mild state, steel, as thus defined, contains more carbon than is generally to be found in wrought iron, and this excess, small as it is, appears to exercise a very important influence upon its qualities. These qualities have been very distinctly brought out in some investigations I have recently had occasion to make on the welding, tempering, drawing, and annealing of steel, and as the results possess a general interest independently of gun-making I shall now place the substance of them before this Section.

First, as to the adaptation of steel for welding. As a matter of every-day practice, we know that steel very low in carbon is capable of welding, and it has frequently been maintained that, without departing from the system of constructing ordnance known as the 'coil system,' great advantage would be realised by substituting mild steel for wrought iron in the making of welded coils. Our distinguished President, Dr. Siemens, who has taken such a leading part in the modern development of steel manufacture, and whose knowledge of the metallurgy of the subject is not surpassed by that of any other person, has held this opinion, and a few years ago he supplied to my firm a sample of mild steel specially prepared for this purpose. It was very low in carbon, containing only about $\frac{1}{10}$th per cent. A test piece cut from the bar as it came from the maker showed the limit of elasticity, or point at which permanent stretch commenced, to be 13·5 tons per square inch, being not much greater than that of wrought iron; and it broke at 23·3 tons, showing that its ultimate strength was also very similar to that of iron, but its ductility was so great that it stretched to the extent of 37·5 per cent. on a length of two inches before breaking. A similar test piece tempered in oil had its elastic limit raised to 24 tons per square inch, and it broke at 28·6 tons per square inch, while its ductility remained nearly the same as before, the elongation being 36 per cent. instead of 37·5. It will be perceived, therefore, that the material was of a very fine quality, and if the results attained with the tempered specimen could have been realised in a welded coil, its superiority over wrought iron would have been very marked

indeed. Two welded coils of equal dimensions were made from this material, and there was no appearance in either case of defect in the welding. Both of these coils were tempered in oil, and one of them was applied as a jacket to a steel cylinder closed at both ends and used for the purpose of determining the pressure exerted by different charges of gunpowder fired in confinement. An exact duplicate of this cylinder was jacketted with a coil of wrought iron of the same dimensions as the steel one, and the two cylinders were used in comparison with each other. Much to our surprise, the cylinder with the steel jacket began to stretch laterally under a pressure which produced no change in the wrought iron coil. The experiment was considered conclusive against the use of steel for welded coils, and no further attempt was made to use it for that purpose.

The duplicate of this steel coil was laid aside, and my attention having been lately recalled to the subject I applied myself to discover the cause of the inferiority displayed after undergoing the process of coiling and welding. I had a test piece cut from the coil in the lengthways direction of the bar of which it was made, and I found the elastic limit was only 12·5 tons per square inch, against 24 tons in the previous tempered test piece; while the breaking point was 19·1 tons, against 28·6 tons in the former case. The loss of ductility was still more decided, the elongation being only 7·5 per cent. instead of 36 per cent. I then had a test piece cut across the welds, and this broke, not at a weld, but through the solid, showing that the welding was perfect. In this case the elastic limit was 12 tons per square inch, the breaking point 20·1 tons, and the elongation 6 per cent. To determine whether the deterioration which the material had sustained was permanent, or whether the quality could be restored, a portion of the welded coil was hammered out in length, and reduced from a piece about 5 inches broad and 2 inches thick to a section of 1 inch square. A test piece from this bar showed a complete restoration of the fine qualities of the steel and a great accession of strength. The limit of elasticity rose to 21 tons, the breaking point to 27 tons, and the elongation to 36·5 per cent. It was remarkable, however, that after this treatment no further increase of strength was obtained by a renewal of the tempering process. The fracture of the test piece from the original bar was slate-coloured, and of the character usually called fibrous. The test pieces from the coil showed a coarsely granular fracture, but in the restored state effected by hammering, the fracture again became slate-coloured and fibrous.

Thinking it possible that the coil might have been overheated in the welding process, I had a pile made with a number of small slabs of the restored material, and welded at a somewhat lower heat than had been applied in making the coil, but test pieces cut across the pile invariably failed at the junctions with a very insignificant strain, showing that the welding heat could not be reduced consistently with sound welds.

In order to ascertain whether it was the heating or the hammering that had injured the welded coil, I had a piece of the material cut from the coil, and restored to a good condition by drawing under the hammer, and then heated up to the welding point, and allowed to cool without being hammered for welding. In this case the fracture showed no change of crystalline structure, nor was there any decided alteration in quality except that the hardening effect of the hammering was removed. It began to stretch at a low limit, namely 12·5 tons per square inch, but its

breaking point was 25·2, which was higher than in the original bar. The elongation remained nearly the same, being 34 per cent., so that the mere heating to a welding temperature without disturbing the particles by hammering had no serious detrimental effect.

I then took a piece of the steel in the restored condition, and after heating it to the welding point, delivered upon it in that state a single blow of a hammer sufficient to crush it into half its thickness. The result was that the flattened piece divided into fissures all round the edges. For the purpose of comparison, I took a piece of wrought iron selected at random from a scrap heap, and treated it in exactly the same manner. The result was that the iron bore the blow, flattening it to the same extent as the steel, without showing the slightest fissure on the edges. These two pieces are now on the table, and it is impossible to examine them without perceiving that the steel, though differing so little from iron in the amount of its carbonisation, was yet, when heated to the welding point, in a state of friability, while the iron remained perfectly plastic. The conclusion was thus confirmed that it is the disturbance of the particles in this friable state. and not the mere heating, which exercises the injurious effect in the welding process.

I was not surprised to find that the coil itself had derived no benefit from the tempering, because although steel, so low in carbon as this sample, is considerably improved by tempering when the piece subjected to the process is of small dimensions, yet when the bulk is considerable the cooling in the oil is not sufficiently rapid to produce any decided effect.

My next experiments were made upon a block of gun steel containing ·34 per cent. of carbon, which had been rejected on account of its deficient tensile strength. A test piece cut from this block as received from the maker began to stretch permanently at 11 tons per square inch, breaking at 29·4 tons per square inch, with an elongation of 24·25 per cent.; but a piece of the same steel drawn out under the hammer at a red heat from a thickness of 5 inches to a thickness of $1\frac{1}{4}$ inches, resisted 19 tons instead of 11 without stretch, and a breaking strain of 33·2 tons against 29·4, with an elongation of 27·5 against 24·25. A piece of the same steel 5 inches long by 4 inches thick, having been tempered in oil, gave a test piece which showed a further increase of strength, with little diminution of ductility. It began to stretch at 23 tons, breaking at 36·5 tons, and elongating 21 per cent. Various attempts were made to weld this steel in a pile of slabs, but it was found impossible to make sound joints, and the steel was even more deteriorated than had been the case with the previous sample; but a piece of this material spoiled in the attempt to weld it, having been drawn out into a bar of an inch square, proved to be far stronger than in the original state. It stood 24 tons per square inch before stretching against 11 tons in the previous untempered state, and 33·6 tons before breaking against 29·4, but the elongation was reduced from 24·25 per cent. to 15 per cent. The fracture in this case was of the same character as in the original test piece, and showed no indication whatever of the previous injury it had sustained by the attempt to weld it. A piece of the same block heated to a welding temperature, and allowed to cool without hammering, gave a test piece which, so far from showing any injury by the heating, resisted a considerably higher strain than the sample taken from the block as it came from the maker. Its stretching point was 16 tons per square inch, its breaking point 33·2

tons, and its elongation 20 per cent. Another block of gun steel containing rather more carbon, namely ·41 per cent., gave the following results. A test piece cut from the block in its original state began to stretch at 14 tons per square inch, broke at 32·5 tons, and elongated 23 per cent. The same cut from a thick lump of the same material which had been tempered in oil resisted 28 tons before permanent stretch, and 43 tons before breaking, with an elongation of 16 per cent., thus showing the much greater effect of the tempering process where the proportion of carbon is increased, but showing also that the loss of ductility by the process becomes more considerable.

It being important to ascertain whether cylinders which have been tempered in oil could be reheated sufficiently for the purpose of shrinking upon a gun, without destroying the effect of the tempering, a test piece cut from the same tempered lump of this steel was heated in melted zinc to a temperature of 750°, and then allowed to cool naturally in air. Comparing its resistance with the piece which had not been reheated, it gave 25 tons per square inch against 28 tons before stretching, and 40·2 tons against 43 before breaking, but its ductility was increased from 16 per cent. to 20·5 per cent., so that although rendered slightly inferior in strength, it was rendered more ductile and tougher by the reheating. Similar experiments made with steel rather lower in carbon showed that the effect of reheating to this temperature was almost inappreciable either in the way of improvement or the contrary, and no degree of sudden cooling from so low a temperature had any distinct effect. On carrying the reheating to still higher degrees the effect of the previous tempering gradually diminished, but was not altogether obliterated even when the temperature was raised to the bright red heat at which the steel had been immersed in the oil for the purpose of tempering. The friability of the steel at a welding temperature became more marked as the percentage of carbon was increased. Of the many samples I tried the highest in carbon was the block already mentioned, containing 41 per cent. of carbon. This steel, like the milder samples, suffered very little from being merely heated to the welding temperature, provided that while so heated it was not disturbed by hammering, but it was so friable at that temperature that it broke into a mass of small crumbs under a moderate blow of the hammer. It was remarkable, however, that the same blow of the hammer which detached them from the block united them in a thin cake on the anvil.

Whether this friability at a high temperature can be corrected by combining other materials with it, is a point upon which my experience casts no light. If it can be so corrected without detriment to the material, the knowledge of how to do it will be an important acquisition to metallurgical science.

Many of my test pieces were taken from rolled steel hoops containing from ·22 to ·35 per cent. of carbon, and all of these showed much greater tenacity than was exhibited by test pieces taken from forged blocks of similar material. It is one of the characteristics of mild steel that it is enormously increased both in strength and toughness by being drawn out either by rolling or hammering, but especially by rolling, which is more uniform in its action than hammering. There can be no doubt that the process of rolling steel tyres may be extended to the production of rolled hoops of great width, and the time may not be distant when we may see a realisation of the prediction made many years ago by Sir

Frederick Bramwell, that we should eventually be able to produce in this manner continuous unwelded cylinders for boiler-making purposes. Steel cylinders thus made and tempered in oil will be in a highly favourable condition for the construction of ordnance, but in order to make them available for longitudinal as well as for lateral strengths it will be essential to have them in much greater widths than existing machines are competent to produce.

All ductile metals derive additional strength by being stretched, but steel does so in a pre-eminent degree. Roughly speaking its modulus of elasticity may be taken as equal to $\frac{1}{1000}$th of an inch per foot for every ton per square inch of tensional strain. This measure of elasticity applies equally or nearly equally to all kinds of steel, but the range of elasticity becomes greater as the strength is increased. Thus steel that will bear 20 tons without permanent stretch will retract $\frac{2}{100}$ths of an inch per foot of length on being released from its load, while steel that will bear 40 tons without permanent stretch will recover $\frac{4}{100}$ths of an inch per foot on the removal of the strain. So also if the weaker specimen which recovers only $\frac{2}{100}$ths of an inch be stretched to a point at which it will sustain 40 tons per square inch, it will be in exactly the same condition in regard to elasticity as the stronger specimen which bore that load in the first instance—that is to say, its range of elasticity will be doubled. This is a very valuable quality, enabling the steel to gather strength as it yields to an imprudent increase of load. As an illustration of the extraordinary strengthening effect of stretch upon mild steel I may mention that a sample of the steel taken from the welded coil to which I have adverted, and which in its original state showed a tensile strength very slightly exceeding that of wrought iron, sustained a load of nearly 85 tons per square inch measured on the attenuated section of fracture.

But much as steel gains in strength by the process of rolling it gains still more by that of wire-drawing. No form of steel is comparable in respect of strength and toughness to that which has been drawn into the form of wire or riband, and in the case of its application in that form to the strengthening of a cylinder it has the additional advantage of admitting of being laid on with a more favourable adjustment of tension than is practicable with a solid hoop of considerable thickness. But, even with wire, the best tensional condition for giving strength to a cylinder can only be approximately attained, owing to the fact, which is commonly overlooked, that, in bending a wire over a cylinder, it is impossible to give the proper degree of stretch to both of its sides. The outer side having a larger circle to describe must necessarily undergo greater elongation than the inside, and in fact, unless the wire be laid on at a far higher strain than would be necessary or beneficial in the case of rings, the inside, acting as a fulcrum to stretch the outside, will assume a state of compression which can only be taken off by expanding the cylinder after the wire has been laid on. The thinner the wire the less will this disadvantage be felt, and for this reason a given area of section is much better in the flat or riband form than either round or square. Great additional strength is given to steel wire by tempering in manganese, and the highest strength is attained by passing the wire repeatedly through the die as a final operation after the tempering process. The effect of this treatment is to put a very hard skin upon the wire, which, though greatly adding to the strength, is very unfavourable for bending, and a very slight injury to the surface greatly conduces to fracture. Ductility

is of paramount importance in wire that has to be coiled at a high tension on a cylinder, and for this reason wire tempered *after* instead of *before* finishing is safer, though not so strong. If this wire be thick, judicious annealing, though it lessens the ultimate strain which the wire will bear, raises in a very marked degree the limit of elasticity. I have found flat steel wire of about ·2 of an inch thick, and of great ultimate strength, begin to stretch permanently at a tension as low as 25 tons per square inch, while after being properly annealed it would bear 35 tons before permanent movement. The explanation of this curious fact is probably to be found in the removal by the annealing process of contending states of tension produced by the drawing or tempering on the inner and the outer portions of the wire. This view is confirmed by the fact that, when the thickness of the riband was reduced to somewhat less than half, this advantage of the annealing process almost entirely disappeared, and the wire was simply softened and rendered more ductile.

Castings of steel, unhammered, are improved by being tempered in oil in much the same degree as the forged material. Test pieces cut from a cast trunnion of steel gave the following results:—Before tempering the elastic limit was 16 tons per square inch and the breaking point 27·8 tons, the elongation in 2 inches being 7·5 per cent. After tempering the elastic limit was 23 tons, the breaking point 37·7 tons, and the elongation was 12·5 per cent., showing a great improvement under every head. The quantity of combined carbon contained in this specimen was ·36 per cent. The objection to the use of cast steel in the unhammered form is that it is liable to unsoundness from air-bubbles; but this, I think, ought not to exclude its use for trunnion rings, which, from their peculiar form, can only be very imperfectly forged. The unsoundness from this cause would be greatly mitigated by casting under pressure, as advocated by Sir Joseph Whitworth.

There is much less sacrifice of ductility or toughness where increase of strength is obtained by tempering than by increase of carbon, and, in fact, the advantage of tempering in oil is so apparent, both in the case of steel castings and of steel which has been either rolled or forged, that there is strong inducement for engineers to avail themselves of the process for increasing the efficiency of the material in nearly all its applications. The saving of the weight of material necessary for a given purpose would amply repay the cost of the tempering, and in the case of bridges of great span, where the strains are chiefly due to the weight of the structure, independent of its load, the economy effected would be far more than proportionate to the increase of tensile strength in the material.

My experiments are not sufficiently extended to enable me to speak definitely as to the best proportion of combined carbon for steel to which the tempering process is to be applied, but excellent results can certainly be attained with steel containing ·35 per cent. of carbon. If the masses to be dealt with are thin less will suffice; if thick, more will be required; but it is quite possible that the mode of applying the oil in the tempering process might be improved so as to render it more efficacious where the bulk of the steel is large.

The Channel Tunnel.

By J. CLARKE HAWKSHAW, *M.A.*, *F.G.S.*, *M.I.C.E.*

[A communication ordered by the General Committee to be printed *in extenso* among the Reports.]

[PLATES V., VI., VII.]

THIS year the Channel Tunnel Company sought to obtain powers from Parliament to enable it to make a tunnel to connect this country with France, by a railway beneath the Channel, and it deposited plans and prepared a Bill for the purpose. The South Eastern Railway Company did likewise. Neither Company obtained a hearing before Parliament, but there have been preliminary inquiries by the Government, the results of which are that they have announced their intention of submitting the whole question to a Select Committee of both Houses, to be appointed early in the next session of Parliament.

The Channel Tunnel Company had proposed to make a tunnel beginning in Dover and passing beneath the shore line, about two miles eastwards of that town, at Fan Hole, near the South Foreland.

The South Eastern Railway Company's plans showed a tunnel beginning at the west end of the undercliff which lies between Folkestone and Abbot's Cliff, and which was to pass beneath the shore line, near Shakespeare Cliff, to the west of Dover.

A Submarine Continental Railway Company was incorporated this year to purchase certain works belonging to the South Eastern Railway, consisting of two shafts, sunk on the foreshore, near Abbot's Cliff and Shakespeare Cliff, in the lower beds of the chalk, and a mile or thereabouts of headings driven in the lowest beds of the same formation. Nearly everything that has been heard during the last twelve months about a Channel Tunnel has emanated from this Company, who maintain that the part of the coast on which the South Eastern Railway Company's works lie is the only place from which the tunnel can be made.

The Channel Tunnel Company has remained silent, relying on an opportunity of proving its case before a Parliamentary Committee. That, hitherto has been denied to it; but the following facts may show that the Channel Tunnel Company's proposal is worthy of consideration, and that the question has not at all been settled by the South Eastern Railway Company's operations.

The Channel Tunnel Company was incorporated ten years ago—in January, 1872—when it had already existed in the less ambitious form of a Committee for four years, viz., from 1868 to 1872, and it comprises among its supporters and advisers those who, nearly seventeen years ago, carried out the first practical investigations, both geological and engineering, which were undertaken with a view to ascertain where and how a tunnel could be made beneath the Channel. Geological surveys were then made which determined the identity of the beds on the two sides of the Channel. The continuity of the same beds across the bottom of the Channel was determined by a sounding apparatus, which brought up specimens from the bottom. The thickness of the chalk was ascertained by borings 500 feet deep, made through it on the two coasts; and a machine, made by Mr. Brunton, for excavating chalk was tested, and was found to work as rapidly and as efficiently as the machine lately used

between Folkestone and Dover, of which so much has been said. All the geological work was done in the years 1865–7; the machine was tested in 1870.[1] Moreover, this same Channel Tunnel Company originated the French Company, and supplied the plans on which their concession was obtained in 1875. Investigations which have since been made have confirmed the results of these earlier inquiries, but have added no new facts of much importance from an engineering point of view.

Having given so much of the history of this Company as seemed necessary, I will now proceed to the general question of the tunnel.

I shall pass by the political, and, in great part, the military side of the question—but the latter cannot be overlooked by the civil engineer, as the terminal point of the tunnel will, in this country, have to be determined by military considerations.

Primarily, the Channel Tunnel question is a geological one. A knowledge of the geological conditions of the ground to be passed through is absolutely necessary for the successful execution of a tunnel under the Channel.

Monsieur Thomé de Gamond was the first engineer who worked at the geological part of the question. With admirable energy and perseverance he devoted much time to the study of the geology of England and France, not confining his labours to the coast line, but continuing them inland. Unfortunately he failed to realise the insuperable difficulties of making a tunnel under the Channel through the formations below the chalk. The result of his labours was the proposal to make a tunnel under the Varne from Folkestone to Cape Grisnez, through the Wealden and Oolitic formations. Monsieur Thomé de Gamond had not neglected to consider the possibility of making a tunnel through the chalk further to the east. He was led to select the line under the Varne, in the belief that, by sinking a shaft on the Varne, the tunnel could be attacked at four points instead of two, and so the work could be more quickly done. In this, I think, most engineers will now agree he was mistaken, and that a tunnel is not practicable on the line which he adopted. In later years M. Thomé de Gamond was associated with those who proposed a tunnel through the chalk, and he signed the plans for such a tunnel, on which the French concession was obtained in 1875. It was in the year 1866 that he proposed a tunnel under the Varne.

For some years before this time, Sir John Hawkshaw had been considering the practicability of a tunnel under the Channel. His large experience in tunnelling led him to see the facilities which the chalk would offer for making such a tunnel. Early in 1865 he obtained the services of Mr. Hartsinck Day, an accomplished geologist, who possessed a knowledge of surveying. Mr. Day spent several months in that year in examining and surveying the cretaceous and underlying beds on the English and French coasts, and prepared for him a geological map, showing the position of those beds along the two coasts. He, moreover, made a conjecture as to their position on the bed of the intervening sea. This survey confirmed the fact—in so far as it was then known from the writings of W. Philips, De la Beche, and others—that the chalk strata overlying the gault are almost identical, bed for bed, on the two coasts.

[1] Trials were made with Mr. Brunton's machine in the grey chalk at Snodland on many occasions. On the 8th September, 1870, it excavated a heading 7 feet in diameter at the rate of 44 inches per hour; on the 20th January, 1871, the rate was 45 inches an hour, and on the 25th February, 1871, it was 49 inches an hour.

To supplement Mr. Day's work, in so far as it related to the Channel, Sir John Hawkshaw employed Mr. H. M. Brunel to take soundings across the Channel, and to ascertain, as far as possible, the nature of the material forming the bottom of the sea. An apparatus was devised for the purpose, by means of which specimens of the sea-bed were obtained. It was found that, instead of the sea-bottom being composed of loose transported material, it was mostly formed of rocks, *in situ*, similar to those seen on the adjoining coasts. This marine survey, carried out in 1865 and 1866, determined the continuity of the upper cretaceous beds across the Channel. It did not confirm Mr. Day's conjecture as to the position of the beds throughout. Specimens of chalk brought up from the bottom showed that the outcrop of the gault near the English coast lay further to the west than Mr. Day had placed it.

It was still necessary to ascertain whether the thickness of the lower beds of chalk, which had been measured in the cliffs on both coasts where all the beds are exposed, was maintained after the lower beds disappeared beneath the sea. Accordingly Sir John Hawkshaw determined to bore through the chalk, at two points, on the English and French coasts respectively. In this costly operation he was assisted by the late Mr. Brassey, Mr. Wythes, and Messrs. Easton. The points selected for the borings were St. Margaret's Bay in England, distant 4 miles east of Dover and about 8 miles east of the outcrop of the lowest chalk beds on the coast, and Ferme Mouron in France, 2½ miles west of Calais and 4 miles east of the outcrop of the same beds on the French coast. These borings showed that the thickness of the lower chalk does not diminish to any extent as we follow it eastwards from the outcrop.

Thus, by the year 1867, the geological information was obtained which was thought to be necessary by Sir John Hawkshaw. Soon afterwards he prepared plans for the Anglo-French Committee, in conjunction with Mr. Brunlees and M. Thomé de Gamond, showing a tunnel through the chalk from St. Margaret's Bay in England to Ferme Mouron in France. (Line A on Plan, Pl. V.)

In 1868 the Anglo-French Committee applied for a concession from the French Government, and a commission was appointed that year in France to examine the question. After various inquiries, and a long correspondence between the two Governments, a concession was obtained in France. A further series of geological investigations was then begun. These were made by French geologists and engineers. I may here remark that before granting the concession, which imposed very onerous conditions on the French Company, their Government obtained a declaration from the Government in this country that the latter did not object to a tunnel in principle. They, moreover, waited until our Parliament had passed a Channel Tunnel Bill authorising the Channel Tunnel Company to carry out certain preliminary investigations.

The French Company were bound by their concession, obtained in 1875, to spend 80,000*l.* (2,000,000 francs) in preparatory works of all sorts, such as investigations, pits, galleries, borings, &c. The conduct of these operations was entrusted to a Committee, presided over by M. Lavalley—so well known in connection with the Suez Canal works. The geological work was assigned to MM. Potier and de Lapparent, mining engineers and able geologists, and they were assisted by M. Larrouse, Hydrographer to the French Navy. They began by repeating and extending, on a more elaborate scale, the marine survey made ten years

before by Sir John Hawkshaw. Using an apparatus of the kind already mentioned, they succeeded in bringing up a great number of specimens of the rocks forming the sea-bed. These soundings confirmed, in all material points, the old survey. In addition, owing to the great number of soundings that were taken, and to the number of specimens from the bottom that could be identified, it became possible to plot, with some accuracy, the junction of the lower chalk and gault from shore to shore, except for a short distance where those beds pass beneath the sands of the Varne. In addition to the marine survey, a second boring was made at Sangatte, and the results of this work—done in 1875-6—were published in 1875-7, in the form of reports, with maps and sections. Since then the French Company—acting under the advice of M. Lavalley and M. Raoul Duval—have sunk two shafts a little to the west of Sangatte, and have driven some short headings, in different directions, through the lower beds of the lower chalk, and they are now driving two longer headings by machinery. This is being done for the purpose of defining the position of the gault and lower beds of chalk.

The researches by the French Company have as yet brought no very novel facts to light, such as to disturb the main conclusions which had been previously arrived at in this country, but they have made our knowledge more definite in several particulars. Their survey shows that there is no break in the line of the outcrop of the gault, such as would be caused by any large fault. It attempts to define the position of the outcrop of the various divisions of the chalk. The position of these outcrops, on the plan accompanying the French Report (1877), indicates a considerable depression in the chalk beds, extending along and not far from the English coasts. Mr. Topley, of the Geological Survey of England, who reported to the Channel Tunnel Company, in 1878, on the French investigations, inclines to think that the view of the French geologists, with regard to the existence of such a depression, is correct. He thinks, moreover, that we may take the position of the outcrop of the gault, as it is shown by them, as being, for all practical purposes, accurate. It differs from that suggested by Mr. Day; but the marine survey made for Sir John Hawkshaw had already shown that the chalk probably extended near the English coast much further to the west than Mr. Day had shown it. We must remember that Mr. Day, in laying down the position of the beds across the Channel, had no other data than he could procure from a study of them on the two coasts.

Since 1880 the South Eastern Railway Company has been carrying on experimental works between Folkestone and Dover. It has sunk two shafts, one near Abbot's Cliff and one near Shakespeare Cliff. A third shaft is being sunk to the east of Shakespeare Cliff. Headings have been driven from the first two shafts, in directions more or less parallel with the cliff, in the lower beds of grey chalk.

The above account is a brief summary of the geological work done up to the present time in connection with the Channel Tunnel question.

As English and French geologists do not employ the same terms in describing the principal divisions of the chalk, I have given a comparative table, showing the divisions recognised in the two countries (see p. 419).

Before leaving the geological part of the question, I will refer briefly to the information that is available, and may be of use in discussing the question of the tunnel, but which has been collected by geologists, not for that purpose, but in furtherance of their own science. Early in this

century the attention of geologists was given to the chalk cliffs forming the south coast of England. Mr. W. Philips read a paper before the Geological Society of London, in 1818,[1] describing the various beds of chalk, showing how constant they were in character and composition at points far apart, and, moreover, that corresponding beds were found on the French coasts of the Channel. These views were confirmed by De la Beche, in 1821.[2] Mr. Hopkins, in 1857, in his account of the structure of the Wealden district and the Bas Boulonnais, deals with the disturbances which affected these beds, as well as others, in the south east of England. The eastern boundary of his 'disturbed district' passes from Abbot's Cliff to Cape Grisnez, just missing the area which any tunnel through the chalk must traverse. Mr. F. G. H. Price contributed a valuable paper, in 1876, on the gault and upper chalk near Folkestone; but it is to Mr. Whitaker and Mr. Topley, of the Geological Survey, that we are indebted for most of the facts, which have been acquired during late years, respecting the beds in question, which facts have been published in the memoirs of the Geological Survey and elsewhere.

In France, Prof. Hébert, Dr. Barrois, M. Potier, and others have added much to our knowledge of the cretaceous beds in that country.

In a few words, the following is a summary of our geological knowledge of the question, as regards the chalk. This is the only formation we need consider, for no other offers equal advantage for the construction of a tunnel. Indeed, through no other formation is a tunnel practicable, taking all things into consideration:—

Identical beds of chalk are exposed above the gault in the cliffs on the two sides of the Channel. These beds are, on the two shores, similar in composition, contain similar fossils, and vary but little in thickness. Taken as a whole, they have a slight dip to the north-east. They have been found to pass uninterruptedly across the bed of the Channel. Borings have shown that the lower beds increase rather than diminish in thickness as they dip below the sea-level to the eastward of their outcrop.

Position and Line of Tunnel.

It will be necessary to assume certain requirements to be fulfilled by the tunnel before proceeding to discuss on what line it will be best to make it. I shall assume that—

1. It will communicate with existing railways in the ordinary way by continuous railway, and not, as has been suggested, by shafts and hydraulic lifts.
2. It will be provided with a means of drainage by gravitation to the shore. That is, the water met with in the tunnel should be able to flow by gravitation from the summit level in mid-channel to the shores of the two countries. This is necessary for safety during construction, and for drainage afterwards.
3. It will be made for two lines of way, and be so designed as to be capable of being worked by ordinary locomotives.
4. The gradient will nowhere exceed about 1 in 80.

Geology has told us the kind of strata which will be met beneath the Channel. The experience of engineers gained in past works can alone determine through which of these strata, and through what part of them,

[1] *Transactions*, Geological Society of London, vol. 5.
[2] *Ibid.*, vol. 1.

it will be best to pass. Before attempting to do so due consideration should be given to the following questions:—

1. What are the military requirements with regard to the tunnel?
2. Where must the tunnel end inland in order to give the best accommodation to existing railways?
3. What are the most favourable strata for the tunnel works?
4. On what line will any error in our geological calculations be of least moment?
5. Which is the shortest practicable submarine line?

The problem, in so far as it depends on surface features of the land and geological conditions, is very different in the two countries, being simpler in France. The points where the tunnel can pass under the shore-line in France are limited by geological conditions to the part of the coast which lies between the Ferme Mouron on the east (where the boring was made in 1867) and Sangatte on the west, a distance of about 2 miles. The country, for some way inland throughout this distance, is low and flat, and, probably looking to military requirements, or to communications with existing railways alone, it is not very material, within these limits, where the tunnel first reaches the coast. The point may be determined wholly by engineering and geological requirements.

The case is very different and much more complicated on the English coast. Geological conditions will admit of the tunnel passing under the shore-line anywhere between St. Margaret's Bay on the east and Shakespeare Cliff on the west, a distance of 4½ miles. With the exception of the valley of the river Dour, which enters the sea at Dover, the land along this part of the coast is high, bounded by chalk cliffs from 200 to 500 feet high.

Such being the nature of the coast, there are only three places where the exit from the tunnel can be made—in the valley of the Dour near Dover, inland in the chalk escarpment to the north of Folkestone, and in the landslip between Abbot's Cliff and Folkestone. In the first case the tunnel would pass under the shore-line to the east of Dover, and in the two latter cases to the west of Dover. At the last-mentioned place, between Abbot's Cliff and Folkestone, the tunnel on the South Eastern Railway has been partially destroyed by a landslip, and the line was blocked for some weeks near Abbot's Cliff by a fall of the chalk in 1876. This part of the South Eastern Railway is liable to be obstructed at any time by larger landslips. For this reason it would be out of the question to place the tunnel mouth on such treacherous ground, even if the place satisfied other requirements, such as facilities for the defence of the tunnel, and for communication with existing railways. Similarly, if the tunnel exit were in the chalk escarpment to the north of Folkestone, it would be near no fortified place, nor could junctions be conveniently made with existing railways. Moreover, this position would necessitate at least 6 miles of land tunnel, in addition to a longer sea tunnel, than from any point of the shore further to the east. The valley of the Dour alone remains to be considered. The tunnel mouth can there be placed at a moderate height above high-water level, which means a shorter length of tunnel and better gradients between the tunnel mouth and the lowest point of the line beneath the sea; it can be placed either within or without the fortifications, as the military authorities may require; and, as the existing railways terminate at Dover, they can with ease be connected by short railways with the tunnel line. It remains to be seen

whether the engineering and geological requirements are as compatible with its terminating at Dover as at the only two other possible places.

I have stated that if the tunnel terminates at Dover it must pass under the shore-line to the east of Dover. This must be so for the following reasons. If we take a gradient of 1 in 80, and assume that the level of the rails where the tunnel passes below the shore-line at low-water mark cannot be less than 100 feet below the surface of the fore-shore, we then require a distance of at least two miles between the point where the tunnel passes under the shore and its mouth inland, supposing it to terminate at a point not much above high-water level. The higher its terminal point is above that level to a greater degree will the required distance exceed two miles. From this it will be seen that, if the tunnel passes under the shore-line to the west of Dover, that is, between Dover and Shakespeare Cliff, it will, if it is to terminate in Dover, have to make a useless circuit of two miles inland. But further than this, the sole advantage which it can be alleged is to be gained by crossing the shore-line west of Dover is that of remaining in certain lower beds of chalk, which have their outcrop near Folkestone, some six or seven miles to the west of Dover; now, this advantage, if it be one, can only be secured by placing the tunnel mouth on the outcrop of the beds in question, that is, in the Folkestone Landslip or on the chalk escarpment to the north of Folkestone. That is to say, the sole reason alleged for going west of Dover precludes the tunnel terminating near that town. From these considerations it will be seen that, if the tunnel terminates in the Valley of the Dour, it should cross the shore-line to the east of Dover, and there are other and far more weighty reasons why the tunnel should leave our coast to the east of Dover.

The plans deposited by the Channel Tunnel Company, this session, show the sea tunnel to begin at Fan Hole, which lies a short distance to the west of the South Foreland Lighthouse. The first line laid down by Sir John Hawkshaw, in 1867, left our coast near the same point. It was afterwards moved to St. Margaret's Bay, further to the east, and was so shown in the plans on which the French concession was obtained. In both cases the tunnel was shown to pass in a direct line to the Ferme Mouron in France.

Now, a line drawn from a point about half a mile east of Fan Hole, to a point about half a mile to the west of the French works at Sangatte, is the shortest line between the two countries, measured from low water to low water, and is about $20\frac{1}{4}$ miles long. From Fan Hole to the Ferme Mouron, in a direct line (Line B on Plan, Pl. V.), is $21\frac{1}{2}$ miles, and from the same place to the boring made in 1876, near Sangatte, is $20\frac{3}{4}$ miles (Line No. 1 on Plan, Pl. V.). Practically this last is as short a line as can well be obtained. For to move the point of departure eastwards in England would be to lengthen the land tunnel in order slightly to shorten the sea tunnel, and geological conditions prevent our moving the line further to the west in France.

As we move the point of departure on the English coast to the west, we increase the length of the most direct line to the French coast, and as we move it to the west of Dover this length is rapidly increased, for the tunnel cannot be made in a straight line from any point in England, west of Dover, but must be made in a curve, deviating considerably from the most direct line. Thus from Fan Hole, or thereabouts, the shortest line for the sea tunnel is obtainable; again, as Fan Hole is distant a little

over two miles from Dover, it is, at the minimum distance, required to pass with a gradient of 1 in 80 from the mouth of the tunnel to the required depth below the shore-line, and thus we get the shortest possible land tunnel. I think that, so far, it has been shown that everything is in favour of the tunnel terminating in the Valley of the Dour, and passing beneath the shore-line near Fan Hole. It remains to be seen how far these advantages are outweighed by any geological conditions afforded by the Folkestone route.

The only reason which has been given for taking the tunnel under the shore-line to the west of Dover is, that by so doing it can be made wholly in the lowest beds of chalk. It is asserted that no water, or very little, will be found in these lower beds. Now what are the facts. We are told that little water is found in the heading from Shakespeare Cliff; that may be so, as far as it has gone. In the headings driven at Sangatte, in the corresponding beds in France, water is met with flowing from fissures at the sides and bottom, and not confined to one place, but throughout the headings. The quantity which I saw was not large—the largest spring, perhaps, 30 gallons per minute—but it is enough to prove that those beds are not impermeable; and no one can assert that where small water-bearing fissures exist, larger ones may not be met with. In the region where a tunnel is possible, the only other evidence we have as to the water-bearing qualities of these beds below sea-level, is that obtained from small borings, few in number, and not of much value as compared with the evidence derived from headings and shafts through the beds. Above the level of the sea we can study the beds at many points. I do not attach much value to deductions as to the probable condition of the beds below the sea-level, made from their observed conditions above the sea-level, for the constant movement of the land waters, from the highest levels to the points where they are discharged into the sea, must produce well-defined drainage-channels underground, which need not necessarily exist at greater depths where there is no such rapid circulation. Still, as much has been made, especially by the French engineers, of evidence derived from observations on the zones from which water is discharged on land, I will give a few facts relating to them. In France water may be seen to flow in many places from the lower beds of chalk, where they appear in the cliffs, between Escalles and St. Pot. I saw water flowing at the very junction of the lowest beds and the green sand. There are some large springs near Escalles, which, on the section accompanying the French Report (1877), are shown at about 60 feet above the upper green sand. The section shows Lydden Spout on the same horizon, but that copious and well-known spring, on the coast between Folkestone and Dover, issues, according to Mr. F. G. H. Price, who carefully measured the cliff section near it, at the top of the so-called 'cast bed,' about 32 feet above the upper green sand, or 46 feet above the gault. Therefore, if this evidence is worth anything, it shows that, on the French side, water might be met with largely, 60 feet above the green sand; or, allowing 36 feet for the depth occupied by the tunnel and its masonry, 24 feet only above the tunnel, supposing it to be driven continuously along the top of the green sand. On the English side, as the water is found only 32 feet above the green sand, the top of the tunnel would be in this water-bearing zone, on the same assumption. It is needless to say that no railway tunnel could be driven along the top of one bed, following all its flexures. Thus, if the evidence from the permeability of the strata on land proves

anything, it is that a tunnel driven in the lowest beds of chalk must come very near a bed from which large springs are discharged on land, and that it will probably have to pass into this bed. I may here remark that it is a fallacy to suppose that if a heading were driven across the Channel in one bed, without meeting with water, it would prove that a tunnel could be driven on the same line equally free from water. The vertical depth of a heading is only 7 feet, that of the excavation for a tunnel would be at least four times that depth. In the Severn Tunnel works, headings have been driven in perfectly dry strata, yet, when the same have been enlarged for the full-sized tunnel, large quantities of water have been met with in the adjoining strata.

It has not only been asserted that very little or no water will be met with in the lowest beds of chalk, but also that so much will be met with in the higher beds as to make it impracticable to tunnel through them. Large numbers of wells have been sunk all over the country, and other excavations have been made at all depths and in all parts of the chalk formation for the purpose of obtaining water, and our knowledge of the mode in which water occurs in that formation is fairly complete. Much has been written on the subject. Professor Prestwich treats of it in his work on the water-bearing strata of London,[1] and gives references to earlier writers, but much information has been gained on the subject since the date of Professor Prestwich's work. In the 'Proceedings of the Institution of Civil Engineers,' from the year 1839 down to the present time, numerous papers on the water-bearing qualities of the chalk may be found, and in the discussions which followed them the most eminent geologists of the day, Dr. Mantell, Dr. Buckland, Professor Ansted, and others, took part.

The following are, I believe, well-established facts on the subject in question.

Solid chalk absorbs a large amount of water, but it parts with it with extreme slowness, so that it cannot be said to be truly permeable. It is only from the fissures which traverse the chalk formation, and from the cavities found along its planes of stratification, that water can be obtained. At a variable depth below the surface of the land the body of the chalk is saturated, and such fissures and cavities as may occur there are full of water, not stationary, but slowly flowing from the higher ground inland, towards the river valleys and sea-shore, where the water can find an outlet. Thus, there is a circulation of water underground, just as there is above ground on other less porous formations. Moreover, as the streams and watercourses on the surface are independent of one another, so are the underground channels in the chalk. If, in excavating chalk, a fissure is cut across, a certain supply of water may be obtained; if a second fissure is cut through, a further supply may be obtained; and generally it will be found that if the water is pumped from one fissure, it does not immediately diminish the flow from adjoining fissures; and, in like manner, if the flow of water from one fissure is checked, it does not necessarily increase the flow from those adjoining. In course of time, lowering the water-level at any fissure will affect the supply to adjoining fissures, inasmuch as all draw their supply from the same saturated mass of chalk; but as a consequence of the extreme slowness with which chalk gives up

[1] *A Geological Enquiry respecting the Water-bearing Strata round London*, by Joseph Prestwich, Junior, F.G.S., London, 1851.

its water, unless there is direct communication between two fissures, operations at one do not generally affect the others. Now this property of the chalk is of the greatest importance in carrying out engineering works which require excavations to be made through the water-bearing levels in it, for it enables the engineer to deal with the water in detail. Fissure after fissure may be cut through as long as the water flowing from them leaves a sufficient margin of unused pumping power; as soon as the yield of water becomes so great as to diminish that margin unduly, some of the fissures may be blocked up with temporary or permanent work. Thus it will be seen that, in tunnelling through chalk, a very large volume of water might be dealt with if it entered the work by separate channels. A very large body of water entering at one point might give trouble, and I shall accordingly select some facts from the very large number available, to show that from no one area of chalk, even of considerable extent, much less from one fissure, has a supply of water been derived larger than could easily be dealt with, or which at all approaches the volumes which have been dealt with on works completed or now in progress. At Goldstone Bottom, one of the pumping stations of the Brighton Waterworks, a greater quantity of water is obtained than at any other locality known to me. Mr. Edward Easton, the best authority on this subject, has kindly furnished me with some particulars respecting these works. There are engines at Goldstone Bottom capable of raising 300,000 gallons an hour, or 5,000 gallons a minute, but it has been necessary to make a length of 1,800 feet of tunnels to obtain the required supply. These are at right angles to the fissures, which here, as is so often the case, are at right angles to the shore-line. At Lewes Road, another of the Brighton pumping stations, there are engines capable of lifting 280,000 gallons an hour, or 4,666 gallons a minute, to supply which 2,400 feet of tunnels have been made. Mr. Easton tells me, and this is the important point, that the water in those tunnels is under complete control, so that any one of them can be laid dry at any time of the year.

The work which has tested to the fullest our power to tunnel through the wettest parts of the chalk is the Brighton intercepting sewer, for which Sir John Hawkshaw was engineer. The main sewer is more than 7 miles long. The outfall is placed on the coast, about 4 miles to the east of Brighton; and, throughout a distance of about 4½ miles, a tunnel, from 9 to 10 feet in diameter, was excavated in the upper chalk, along the base of the cliff, and close to the shore. Being below high-water level, it cut through all the fissures which discharge the drainage of a large tract of inland chalk country. Large fissures were cut through, which I had frequent opportunities of inspecting, and, moreover, of seeing the permanent work successfully carried across them. The greatest quantity of water pumped at one time was 10,000 gallons a minute, or 600,000 an hour; many other examples might be given, but none so striking as the above. It may be urged that, by going below the levels reached by the above works, more water would have been obtained, but that by no means follows. The Brighton Sewer Works must have intercepted most of the land drainage; by going deeper, some water, stored in cavities below sea-level, might have been pumped. But the supply depends not on the quantity stored, but upon the rate at which the fissures can deliver it. Fissures there are, or, there have been, at all depths; but, as the circulation is not so rapid in the deeper ones, they are more liable to be choked

by sedimentary and crystalline deposits. Deep mines are often very dry ones.

As an example of water-supply obtained from deep down in the chalk, we may take the supply drawn from the London basin. Below London we have a great thickness of both the upper and the lower chalk, amounting together to more than 600 feet in places. As this chalk, so far as we know, rests in a basin of gault clay, and rises in continuous beds to form the high ground to the north and south of the London basin, it is in the best position to be saturated with water, and such was its condition before it was made use of as a source of water-supply for London and its neighbourhood. As the supply from the shallow wells made in the tertiary beds became exhausted, deeper wells were sunk into the chalk beneath, and water was obtained in plenty. But the supply soon ceased to be equal to the demand; the level of the water in the chalk was depressed, so that wells had to be deepened, and new adits made to cut new fissures. In 1838 the quantity pumped[1] in London was estimated at 6,000,000 gallons a day; in 1850 the quantity had increased to not more than 12,000,000 gallons a day. In the meantime the level of the water in the chalk had been depressed in some places 50 feet. Thus the larger quantity could only be obtained at a greater depth, and by increasing the fall in the fissures delivering the water to the pumps. Now this chalk, from which only a limited supply could be obtained at a given depth over a large area, was connected on all sides with an unexhausted reservoir, at a much higher level, formed by the saturated masses of chalk round the London basin, and yet the water-level in it was reduced by a comparatively small amount of pumping.[2]

Before leaving the subject of the quantity of water found in carrying out particular works, I will refer to two tunnels now in progress, although they are not being made in the chalk formation.

The Mersey Tunnel, which is being made under the direction of Mr. Brunlees, one of the engineers of the Channel Tunnel Company, will connect Liverpool and Birkenhead by means of a railway. It is $2\frac{1}{4}$ miles long, of which nearly three-quarters of a mile is beneath the Mersey. Shafts have been sunk, and a heading has been driven for a quarter of a mile, and the main tunnel for 600 yards, through the pebble beds of the New Red Sandstone. Mr. Brunlees tells me that the greatest quantity of water pumped amounted to 6,000 gallons a minute. This quantity is being gradually reduced by lining and tubbing.

The Severn Tunnel is in a more advanced state; and as it illustrates many of the points to which I have referred, and as I have been continually on the works during the last three years, I shall refer to it at greater length. The Severn Tunnel will be the longest railway tunnel in England, in all $4\frac{1}{2}$ miles in length; and it is the only railway tunnel which can claim to be submarine. It passes, for $2\frac{1}{2}$ miles, below a tideway where there is

[1] *Minutes of Proceedings of Institution of Civil Engineers*, vol. ix. p. 161 (Homersham).

[2] *Minutes of Proceedings of Institution of Civil Engineers*, vol. ix. p. 165 (Braithwaite), p. 155 (Clutterback), and p. 168 Braithwaite, states Messrs. Combe bored 300 feet into chalk, and only obtained 25 gallons a minute; Meux & Co. bored 160 feet, obtaining only 10 gallons a minute; Messrs. Reid & Co. laid open an area of 1,600 feet of chalk, and only obtained 200 gallons a minute; p. 172 Homersham admits depression of water-level under London; p. 175 Taberner admits depression of water-level under London; p. 176 Horne says, water at St. Luke's depressed 21 feet between 1841 and 1850.

a rise of tide of 40 feet, and a depth of water at high water of 90 feet in the deepest part of the channel. It passes, for a considerable portion of its length, through the Triassic red marl, which has many points of resemblance to the chalk. The marl, which is in nearly horizontal beds, is much fissured, and from these fissures, as well as from spaces between the planes of bedding, much water is discharged. At the English end of the submarine part of the tunnel, for some distance, there is only from 35 to 40 feet of this open-jointed red marl above the brickwork of the tunnel, which is already finished where the cover is thinnest. Salt water flows freely into the work; and, to show how the water-channels are disconnected, salt and fresh water have, in some cases, flowed from adjoining fissures, and the fresh water has been allowed to flow, for drinking purposes, through pipes built into the brickwork. The largest quantity of water has been met with on the land portion of the tunnel; and the largest spring met with was in the land tunnel. It discharged 5,000 gallons a minute, and burst suddenly into a heading, which had been driven for over 1,000 feet, in millstone grit, without meeting with any water. If the heading had been driven at a level of 10 feet lower, the spring would have been avoided in the heading, but would have been met with when it was enlarged to the full size of the tunnel. The total quantity of water now being pumped is between 7,000 and 8,000 gallons a minute.

The examples I have given show that engineering works need not be stopped, even by large quantities of water; and, much as we know of the chalk and its water-bearing qualities, there is nothing to show that water would be met with in such large quantities as to stop tunnelling, even in the upper chalk with flints.

A tunnel can be made from Fan Hole, in a direct line to the French coast, wholly in the upper part of the lower chalk without flints, as will be seen from the section of Line No. 1 of the Plan, Pl. V.; but, as has been already stated, a tunnel could be made from the same place, if it were advisable, for nearly three-quarters of the whole distance, in the lowest beds of grey chalk. To do this, it would be necessary to curve the line of tunnel southwards, after leaving the shore, and then eastwards, as shown on the plan in Line No. 2, Pl. V. This would make the sea tunnel nearly 1½ miles longer on Line No. 2 than on Line No. 1, Pl. V. That is, the certain immediate cost of making 1½ miles of tunnel with the prospective disadvantage of 1½ miles more sea tunnel, to work, maintain, and ventilate, would be incurred, to save the cost of *possible* excess of pumping on the one route over the other.

Whatever may be urged as the advantage of attempting to follow these lower beds, there are some very obvious disadvantages and positive dangers in attempting to do so.

In the beginning of these discussions respecting the tunnel line, certain questions were given as necessary for consideration. Of these, the third was:—On what line will an error in our geological calculations be of least moment to our tunnelling operations? The map and sections, to which I have referred, are all based on the result of the French Company's work. The marine and geological survey was made with care and precautions such as were probably never before taken, and is an admirable piece of work. As long as it deals with the surface of the sea-bottom, the reports and accompanying plans and sections probably tell us a true story, on which we may rely. But when we pass from the surface of the sea-bed to the strata beneath, we go from facts to conjectures. A longitudinal section

(Section E, F, Pl. VII.), down the centre of the Channel, shows the chalk from where it begins, at the outcrop of the gault, dipping at first rapidly beneath the sea, the dip gradually diminishing as we go eastwards. Now the part of this section in which error is most likely to be found is in the curve which denotes the base of the chalk near the outcrop. For the curve showing the base of the chalk depends not only on the position of the line on the map which shows the junction of the chalk and gault, which is, probably, in the main, correctly plotted, but also on the line which shows the junction of the two lowest beds of chalk of the French geologists (Craie de Rouen and Craie Moyenne). It would be very rash to take this last line as other than approximate; yet all it could tell us, if it were correctly plotted, would be the dip of the base of the chalk close to the sea-bed, and, even to get that, we should have to assume the thickness of the Craie de Rouen from its ascertained thickness on the two coasts. Of the dip a short distance below the sea-bed we really know nothing, and the curve indicating it must be imaginary. If the tunnel is to follow the lower beds of chalk it will have to be near this curve line; and any variations in the curve will necessitate deviations in the line of the tunnel, so that its length might be largely increased. This continual deviation of line would add much to the difficulties of construction. Again, the lower the beds in which the tunnel is placed, and the nearer to the outcrop of those beds, the greater will be the risk of water finding its way along the planes of bedding from the outcrop.

As we pass from the outcrop of the base of the chalk and the gault, in an easterly direction along the Channel, the chalk increases in thickness. On Line No. 1, the chalk is 480 feet thick, while on Lines Nos. 2 and 3 it is about half that thickness; and, with the same thickness of chalk over the tunnel, there would, on Line No. 1, be 245 feet more chalk below the tunnel than on Lines Nos. 2 and 3. An error therefore which would necessitate a considerable deviation in the line of tunnel on Lines Nos. 2 and 3 would not in any way affect No. 1; for it would require an error altering the position of the whole mass of chalk, vertically 245 feet, to disturb the tunnel line if made in direct line between Fan Hole and Sangatte, that is on Line No. 1. (See Plates V. and VI.)

I have given a third section across the Channel, along the line numbered 3 on the plan, and the position of a tunnel is shown on it in continuation of that shown on the section deposited by the South Eastern Railway Company. This tunnel does not keep wholly in the lowest beds of chalk, so that it does not fulfil the requirements which a tunnel beginning to the westwards of Dover should. That it may do so, one of two things must be done: the line of the tunnel shown on the plan must be depressed some 130 feet so that it may follow the lowest beds across the depression shown on the section, or we must bend the line No. 3 shown on the plan more to the west, so as to follow the lowest beds of chalk, where they are found at a higher level nearer to their outcrop. The first course would render it impossible to make a drainage heading to the shore in the chalk; for the tunnel would be so low, at its lowest point, that it would not be practicable to obtain a fall in the chalk to the shore. This drainage heading has been already stated to be a necessity. The alternative remains, but it would make the submarine tunnel at least one mile longer than Line No. 3, which is already three miles longer than Line No. 1 from Sangatte. That is to say, to avoid passing out of the lowest beds of chalk, the total length of tunnel would be increased by nearly

four miles, besides incurring the other disadvantages of the Folkestone route. Four miles of sea tunnel would not cost far short of a million, an amount which would pay for 4,000 horse-power at work, night and day, pumping for nearly seven years—a power which would raise more than 40,000,000 gallons each 24 hours.

In deciding on the best line for the Channel Tunnel, the quantity of water which may be met with is but one of many factors to be taken into account. The Folkestone route would sacrifice all those of known value for the one of which the value is least certain.

No tunnel will ever be driven under the Channel without meeting with some water, and an attempt to make one without ample preparations for dealing with a large quantity of water will only lead to waste of money, and, perhaps, failure.

The following is a summary of the advantages to be obtained by making the tunnel in a direct line from Fan Hole to Sangatte:—

The shortest sea tunnel.

As short a land tunnel as by any line.

A greater thickness of chalk through which to tunnel.

The best termination for effecting junctions with the existing English railways.

A termination affording facilities for defence at a less cost than elsewhere.

No certain advantage can be claimed for the Folkestone route, and, as compared with the route to the east of Dover, it has the following disadvantages:—

The sea tunnel must be, at least, three miles longer.

The land tunnel must be four miles longer, unless the mouth is placed in the Folkestone landslip.

The chalk on the line of tunnel will be only half the thickness—in round numbers 250 feet against 500 feet.

It will emerge near no fortifications, nor can it be connected with the London, Chatham, and Dover Railway Company's line at Dover.

Further, this tunnel must be made, for a great part of its length, near the outcrop of the beds through which it is driven.

Ventilation.

One of the requirements to be fulfilled by the tunnel, which was mentioned early in the discussion, was that it should be so designed as to be capable of being worked by ordinary locomotives.

A machine may be invented which will be capable of carrying on the traffic, economically and expeditiously, through a tunnel such as the Channel Tunnel; but no machine is known, or has been tried up to the present time, that is capable of doing the work so economically or so conveniently as the ordinary locomotive. Until such has been tried and proved equal to the work, it would not be prudent to spend some millions of money in making a tunnel which could not be worked by the ordinary means. It may be taken as an accepted fact that a Channel Tunnel worked by an ordinary locomotive would require artificial ventilation. The matter was discussed, at some length, at a meeting of the Institution of Civil Engineers, in 1876, when Mr. Morrison read a paper on the subject. Most extravagant estimates were then made of the number of

horse-power required to ventilate the tunnel. The paper itself, and an account of the discussion which followed, will be found in the Minutes of the Proceedings of the Institution of Civil Engineers.[1]

If the attempt be made in a tunnel, 20 miles long, to create, artificially, a sufficient velocity in the air to maintain it in a state of even comparative purity, the difficulties will be found to be very great; but, if it be divided into sections, each 5 miles long, and these sections be treated separately, the difficulties in a great measure disappear.

The distance between the ventilating shafts of Line No. 1 would be about 21 miles; but, to simplify the calculations, assume a tunnel 20 miles long, with descending gradients of 1 in 80 to points distant 5 miles from each shore, and rising gradients from thence of 1 in 1,000 for the 5 miles to the centre. (See Plate VII.) The drainage headings, each with a falling gradient of 1 in 1,000 to the pumping shafts on the shore, will begin at the lowest points of the tunnel, midway between the centre and the shores where the two gradients meet.

If the main tunnel be circular, with an internal diameter of 30 feet and an area of 470 square feet above rail level, air-passages may be formed below the rails, having an aggregate area of 106 square feet. The drainage heading may also be circular, with an internal diameter of 17 feet, and a sectional area of 227 square feet. This will not be much in excess of what is required during the construction of the tunnel, for the greater part of the material excavated and materials for construction will be taken out and in through the drainage heading.

If air be now drawn out of the drainage heading with a velocity of 10 miles an hour, it will produce a velocity in the tunnel of 2·25 miles an hour, supposing the air exhausted from the tunnel to be replaced at the shore ends from the shafts and at the centre from the air-passages below the rails. If 48 trains pass through the tunnel in 24 hours, at intervals of half an hour, the air will remain pure at the shore ends and in the centre. Between those points, the quantity of carbonic acid, in excess of that normally contained in air ($3\frac{1}{2}$ parts per 10,000 of air), will gradually increase, until it reaches a maximum at the points midway between the centre of the tunnel and each shore, where it will amount to 12·68 parts per 10,000 in excess, or 16·18 parts altogether.[2] The average condition throughout the tunnel will be 6·34 parts in excess, or 9·84 parts in all. Dr. Angus Smith, in his work on air and rain, states that in his own study he found 10·4 parts of carbonic acid per 10,000 parts of air. In theatres, it has been found to vary from 20 to 32 parts; in the Chancery Court, between 19 and 20 parts; and the air in a first-class carriage, between Gower Street and King's Cross, with the windows open, contained 22·5 parts per 10,000 of air. Thus it will be seen that, if such a state of things as is described above could be maintained in the tunnel, there could be no cause of complaint. To do this in a tunnel 20 miles long would require about 460 effective H.P., or 230 effective H.P. in each country. In a tunnel in a direct line between Fan Hole and Sangatte about 500 effective H.P. would suffice. The cost of keeping

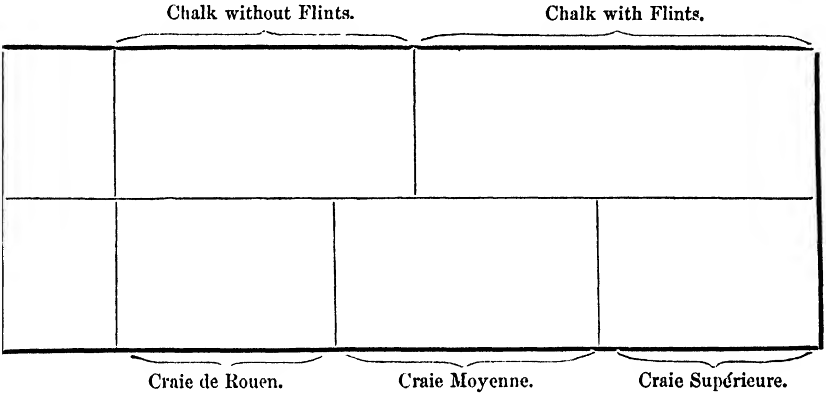
[1] Vol. XLIV.

[2] In these calculations the quantity of carbonic acid produced per train mile has been arrived at on the assumption that each pound of carbon consumed produces $31\frac{1}{4}$ cubic feet of carbonic acid, and that the average consumption of carbon would be 25 lbs. per train mile.

this amount of H.P. at work would be a mere fraction of the working expenses of the tunnel, which, for many reasons, should not be as heavy as those of other lines.

COMPARATIVE TABLE

SHOWING THE PRINCIPAL DIVISIONS OF THE CHALK ACCORDING TO ENGLISH AND FRENCH GEOLOGISTS.



SCALE FOR COMPARATIVE TABLE.

The Forth Bridge. *By* B. BAKER.

[A communication ordered by the General Committee to be printed *in extenso* among the Reports.]

[PLATE VIII.]

AT the request of Dr. Siemens the following short paper on the proposed Forth Bridge has been prepared, though the author himself would have preferred to postpone any communication on the subject to the British Association until the works were well in hand, and the many points of interest and difficulties inseparable from so gigantic an undertaking had manifested themselves. At the present moment a commencement has not been made, the whole period, from the revival of the project last year until now, having been occupied in the necessary preliminary work of obtaining the Act of Parliament and preparing the designs and specifications. It is believed, however, that in a few weeks the contract will be let, and an energetic start will at once be made with the works.

Before referring in detail to the history of the undertaking and to the character of the design, the author would like to convey, if possible, some notion of the magnitude of the proposed bridge across the Firth of Forth. In preparing the detailed designs he has often experienced no little difficulty in realising the scale upon which he was working. For example, the bed-plates for an ordinary railway girder bridge, say a couple of hundred feet span, would be about half the size of an ordinary dining-*table*, and it is difficult at first to picture to oneself a bed-plate about double the size of an ordinary dining-*room*; but that is the size of the bed-plates for the Forth Bridge girders. A diagram hanging on the wall showed the comparative sizes of some of the largest girder and arched bridges in the world; but even this failed, in the author's opinion, to impress upon the mind the vast difference in scale between the proposed and all previous bridges. On glancing through the last volume of 'Reports of the British Association,' with a view to obtain a notion as to the ordinary length of papers for Section G, he incidentally obtained a notion also for illustrating, in popular but perfectly accurate terms, the size of the Forth Bridge as compared with the largest bridges in this country. In the Report of the Anthropometric Committee it was stated that the average stature of a new-born infant is 19·34 inches, whilst the average height of the Guardsmen sent out to Egypt has been officially given at 5 feet $10\frac{1}{2}$ inches. These figures have a ratio of 1 to 3·65, and, singularly enough, as the largest railway bridge in this country, the Britannia Bridge, has a span of 465 feet, and the Forth Bridge a span of 1,700 feet, the ratio there also is 1 to 3·65. Hence, to enable anyone to appreciate the size of the Forth Bridge, we have merely to suggest the following simple Rule of Three sum:—As a Grenadier Guardsman is to a new-born infant, so is the Forth Bridge to the largest railway bridge yet built in this country. Bridges a few feet larger in span than the Britannia have been built elsewhere, but they are baby bridges after all.

Such being the size of the structure, the question naturally occurs, why it should be necessary or expedient to build so unprecedented a work far north in this little island of Great Britain, when it has been found practicable to cover the globe with railways, and to carry roads across the greatest Continental rivers, without involving any such difficult undertaking. The answer is a somewhat complex one. It is not the physical features of the country, but the habits of the population that render the construction of a 1,700-feet span expedient. If the British public can save a few minutes by going a particular route, by that route will they go, although the alternative one might be as eligible, or even more so, in every other respect. This fact was forced upon the attention of the North British Railway Company nearly twenty years ago, when they sought powers to construct a bridge across the Forth, to secure for themselves and their allies the Great Northern, North Eastern, and Midland Railways, a fair share of the through traffic between England and the north of Scotland, which they alleged had been hitherto practically monopolised by the London and North Western and the Caledonian Railways, whose route was a few miles shorter. Parliament, satisfied, no doubt, that the contention was a reasonable one, granted the solicited powers in the year 1865. The bridge then proposed crossed the Forth at a different spot to the present bridge, as the engineer had not the courage to face a span of 1,700 feet, and nothing less is practicable at Queensferry. Owing to the treacherous character of the foundations, however, it became

necessary to adopt another site, and by bringing the point of crossing five miles further down stream to Queensferry, a considerable saving in distance was effected in the route between Edinburgh and Perth.

The Act for constructing a bridge at Queensferry was obtained in 1873. At this point the Firth of Forth is divided by the island of Inchgarvie into two unequal channels, but the depth of water in each is such that a smaller span than 1,700 feet could not be economically adopted for either channel. North of Inchgarvie the maximum depth of water is 218 feet, and south of the same 197 feet. In the former channel the bottom is of hard trap rock, and in the latter partly of rock and partly of extremely stiff boulder clay. It is not the treacherous character of the bed of the Forth, therefore, but the depth of water which precludes the construction of intermediate piers. Pneumatic apparatus is inapplicable to such depths as 200 feet, and no responsible engineer would care to found the piers of an important structure upon a bottom which he had no means of examining by diving apparatus or otherwise.

To the late Sir Thomas Bouch is due the credit of the bold proposition to cross the Forth in two spans of 1,600 feet, and so to avoid the necessity of intermediate piers in unprecedented depths of water, with all the consequent uncertainties and contingencies. A contract for the construction of Sir Thomas Bouch's great suspension bridge was made with Messrs. Arrol, and the preliminary works were in progress when the Tay Bridge fell. In consequence of the latter catastrophe the directors of the Forth Bridge Company decided not to proceed with the works, and an Abandonment Bill was consequently promoted in the Session of 1881. The North British, Great Northern, North Eastern, and Midland Railway Companies, being interested in securing direct communication with the North of Scotland, objected to the abandonment of the enterprise, and instructed their respective consulting engineers, Mr. Fowler, Mr. Harrison, and Mr. Barlow, to report anew on the practicability and cost of crossing the Forth, either by a bridge or otherwise, at Queensferry or elsewhere. A careful re-investigation of the whole question was accordingly made, with the result that the directors were advised that it was perfectly practicable to build a bridge across the Forth which would comply with all the requirements of the Board of Trade and public safety, and that the best place of crossing was at Queensferry. The Abandonment Bill, which had passed the Commons, was then withdrawn, and the engineers were instructed to agree upon a design. Modifications of the original suspension bridge were first considered, and Mr. Fowler and the author then submitted a project for a bridge on the continuous girder principle. Mr. Harrison and Mr. Barlow, fully appreciating the advantages which would pertain to such a bridge as compared with a more or less flexible suspension bridge, made independent investigations, and suggested several modifications. Finally, the design now before you was unanimously agreed upon by all as the one to be recommended to the directors for adoption. The directors acted upon this recommendation, and, accordingly, the necessary plans were deposited, and an Act was obtained this year for constructing a continuous girder bridge across the Forth at Queensferry, having two spans of 1,700 feet, two of 675 feet, fourteen of 168 feet, and six of 50 feet, and giving a clear headway for navigation purposes of 150 feet above high-water spring tides. For this work Mr. Fowler and the author are acting as engineers.

It would probably be conceded by everyone that a girder bridge would

prove stiffer than a suspension bridge; but it is not so obvious that it would also be cheaper. Careful comparative estimates have, however, proved this to be so in the case of the Forth Bridge, and the reason is not far to seek. In a long span bridge the weight of the structure itself constitutes the chief portion of the load, whilst the pressure of the wind is at least as important an element as the rolling load itself, to carry which is the sole useful mission of the bridge. In a properly designed continuous girder for a long span bridge the mass of metal will be concentrated near the piers, where it will act with the smallest leverage and produce the least bending moment. In an ordinary suspension bridge, with stiffening girder vertically to provide for the rolling load, and horizontally to meet wind stresses, the mass of metal will be somewhat greater towards the centre of the bridge than at the piers, and consequently for a given mass the moment will be much less in the continuous girder than in the suspension bridge. Thus the Forth Bridge superstructure weighs but 2 tons per foot run at the centre of the 1,700 feet span, and 13½ tons per foot run at the piers; whilst in a suspension bridge, as already stated, the weight of superstructure per lineal foot would be somewhat greater at the centre than at the piers. This consideration, coupled with the facts that suspension links are more costly than girder work, that a suspension bridge requires a very costly anchorage, and that the contingencies and risks during erection in a stormy estuary are very great, explains why, in such a case as the Forth Bridge, well-designed continuous girders form a cheaper, as well as a far stiffer, structure than a suspension bridge with stiffening girder.

Continuous girders, as a rule, are made of uniform depth, and it has been considered by some engineers a rather strained application of the term to so describe the Forth Bridge girders. But clearly it is the nature of the internal stresses, and not the external appearance of the girder, which should decide the question; and from this point of view the proposed Forth Bridge is in the strictest sense of the words a continuous girder bridge. By all authorities a beam is considered to be continuous if it is either rigidly or partially fixed as well as supported at each end in such a manner that a pair of equal and opposite couples act on the vertical planes at its points of support. In the case of the Forth Bridge, such continuity is attained by connecting together the ends of the two 1,700 feet spans at Inchgarvie, and by projecting the other ends a distance of 675 feet beyond the main piers, and weighting them to the required extent. The moment of the couples and the position of the points of contrary flexure in a continuous girder may be regulated at will, either by putting an initial stress on the girder or by severing either the top or bottom member at the desired point. In the case under consideration, the latter method has been adopted, and the question of the most advantageous position for the points of contrary flexure was a subject of elaborate investigation, as it was known to have a vital influence on the economy of the design. Having reference to all the conditions of the problem, it proved to be most advantageous to fix the points at a distance of 675 feet from the piers, so that in effect the 1,700 feet girder may be considered as made up of two cantilevers each 675 feet in length, and a central girder 350 feet in span.

Similarly, on investigation, the most generally advantageous depth proved to be about 50 feet at the centre, and 350 feet at the piers; and, this being settled, the next thing to be determined was the most advan-

tageous width for the superstructure. Since the fall of the Tay Bridge, engineers generally, and the Board of Trade in particular, have vividly realised the fact that the severest wrench to which a railway viaduct is subject arises not from the vertical stress due to the loading of both lines of rails with locomotives throughout, but to the diagonal stress due to the combined action of the ordinary rolling load and a violent hurricane. In the case of the Forth Bridge this stress would act at an angle of about 45°, so that, were it not for the dead weight of the structure, the required strength would be the same horizontally as vertically, and the economical width would be the same as the economical depth. Although the dead weight modifies this conclusion, it was obvious that the bridge should be a continuous girder of varying depth on plan as well as on elevation, and investigation showed the economical width of superstructure to be about 32 feet at the centre, and 132 feet at the piers.

It was open to consideration whether the wind stresses should be resisted by bracing together both the top and bottom members of the girder, or the bottom members alone. The author, however, never had any doubt that, as the stresses must sooner or later be brought down to the masonry piers, they had better be brought down at once by the shortest route along the bottom members only. The top members are therefore spaced at the distance of from 33 feet to 27 feet apart, centre to centre, and are unconnected by wind-bracing. Each of the main vertical and diagonal struts consists of a pair of tubes spread out at the base like a bridge pier, and the wind stresses on the bracing between the tubes are much reduced thereby. In like manner are the wind stresses on the bracing of the bottom member reduced by the spreading out of the legs of the cantilevers, and the general stresses on the web members by the tapering depth from the piers towards the ends of the cantilevers.

Having thus blocked out the general outline of the girder so that the shearing stresses from the diagonal action of the wind and load should be largely taken up direct by the main members, the next point was to determine the number of bays, and the angle of the web bracing. It was not infrequently assumed that 45° was the most economical angle, but this was true only when the admissible stress was the same in compression as in tension, which was not the case either with wrought iron or steel, or where, as in the instance of wind-bracing, the diagonals were subject to alternate compressive and tensile stresses. American bridge builders, as a rule, disposed their long slender struts vertically, and their diagonal ties at an angle of 45°, and as the question of competition entered into the problem, it might safely be assumed that economical considerations dictated this arrangement. The general slope of the web members of the Forth Bridge was something between the angle of 45° and the vertical, and, although the author was not prepared to contend that the disposition adopted was the most economical attainable, yet he was satisfied that it reasonably approached that limit.

Whatever the angle of the bracing, it was quite clear that, in a girder of 1,700 feet span, exceptionally long struts would have to be provided, and it was a matter of much importance, therefore, that the struts and compression members generally should be of the most economical and efficient form. The advantages offered by a circular form of cross-section were self-evident. A flexible sheet of drawing paper, simply rolled upon itself, became transformed into a stiff column, as everyone accustomed to

handle plans and drawings well knew. Similarly, a thin sheet of iron or steel, bent into a tubular form, without further stiffening, offered as high a resistance per square inch to compression as the most heavily braced rectangular strut. The author recently tested a piece of ordinary stove-pipe, 4 inches in diameter and 2 feet long, made of sheet iron only about a fortieth of an inch in thickness, and found it stood, without buckling, a compressive stress of 15·9 tons per square inch, whereas one of the Britannia Bridge rectangular cells, 18 inches square and 8 feet long, made of plates and angles half an inch thick, crippled under a stress of 13·6 tons, or say 15 per cent. less stress than that sustained by the piece of stove-pipe. If flat plates, as much as half an inch in thickness, behaved so badly in a rectangular cell only 18 inches square, it is hardly necessary to speculate as to what would be the case in tubes 12 feet square, which would be the size required for the Forth girders. With rectangular struts formed of four corner-pieces and lattice sides, the required strength of the lattice-work has been found by experiment to be considerably greater than theory would indicate, and the form, therefore, is a very disadvantageous one as compared with a circular cross-section where every particle of metal performs useful work. In a long span bridge, it is essential to reduce the secondary bracing to a minimum, because the weight of metal itself constitutes the chief load. For that and for many other reasons, including the comparatively small resistance offered by a curved surface to the wind, the author, after carrying out not a few experiments himself, and passing in review the numerous experiments made by others during the past thirty years, was satisfied that a circular form of cross-section was the proper one in the case of the Forth Bridge. All the main compression members, therefore, will be tubes varying in diameter from 5 feet to 12 feet, and only the wind bracing, subject to alternate compressive and tensile stresses, will consist of rectangular latticed members.

Between the two main girders, as described above, the double line of railway will be carried on an internal viaduct, supported by trestles and cross girders. The permanent way will consist of heavy bridge rails on longitudinal sleepers bedded in four steel troughs, the outer pair of which serve also as the top members of the girders of the internal viaduct, the inner pair being simply rail-bearers. The width of trough is such that, in the event of derailment, the wheels will drop into the troughs, and run along the timber sleepers clear of obstruction. A buckle plate floor and parapet or wind screen will be provided of ample strength to ensure the safety of the trains. No guard rails will be introduced, as the engineers and the Board of Trade are in accord in considering them a source of danger during high winds.

It is hardly necessary to state that the whole of the superstructure will be of steel. For the tension members the steel used is to have an ultimate tensile strength of not less than 30 tons nor more than 33 tons per square inch, with an elongation of 20 per cent. in a length of 8 inches. For the compression members the strength is to be from 34 to 37 tons, and the elongation 17 per cent. In making the tubes and other members, all plates and bars which can be bent cold are to be so treated, and, where heating is essential, no work is to be done upon the material after it has fallen to a blue heat. The steady pressure of hydraulic presses is to be substituted for hammering wherever practicable, and annealing will be required if the steel has been distressed in any way. No punching or shearing will be allowed, and all plates will be planed at the edges and butts, and all holes

drilled through the whole thickness of plates and angles after being put together.

Previous to the preparation of the designs and estimates, many consultations were held with the Board of Trade officers with reference to the maximum wind-pressure to be provided against, and the admissible stress upon the metal. Existing rules limit the stress to $6\frac{1}{2}$ tons per square inch, and it was desired to get this limit extended to $7\frac{1}{2}$ tons. This was assented to by the Board, as the $6\frac{1}{2}$ tons working stress was based upon the assumption of the steel having a minimum ultimate tensile strength of 26 tons per square inch, whereas the Forth Bridge steel was to have a strength of at least 30 tons. As regards wind-pressure, the present Board of Trade provision of 56 lbs. per square foot has been adhered to, and that pressure has been assumed to take effect upon a surface equivalent to double the plane surface of the bridge, a deduction of 50 per cent. being made in the instance of the cylindrical surfaces. Under the combined action of the wind-pressure, estimated as above, and a rolling load of two tons per foot run, or 3,400 tons on each span, the maximum stress would in no case exceed $7\frac{1}{2}$ tons per square inch, whilst upon the members of the wind-bracing, subject to alternate compressive and tensile stresses, it would not be greater than 5 tons per square inch. In ordinary working—that is to say, with heavy coal trains and light winds—the maximum stresses would be about 6 tons in tension and 5 tons in compression, which were about the same as the Saltash Bridge of 460-feet span would be subject to under the same circumstances, and that bridge is of iron. Even assuming that such a hurricane as 56 lbs. per square foot could ever take effect over so large a surface as that offered by the 1,700-feet girders, it was quite clear that no train could be on the bridge at the time, for a pressure of 30 to 40 lbs. would certainly stop the progress of any train. Without the rolling load the maximum stresses during the hurricane would, however, be only about $4\frac{3}{4}$ tons in tension and 6 tons in compression. Indeed, if the Forth Bridge were made of iron instead of steel, it would be a relatively stronger structure than either the Britannia or Saltash Bridge, so that the 50 per cent. extra strength due to the adoption of the steel may be regarded as an addition to the factor of safety, and not as a necessity of the unprecedented length of span.

Continental and American engineers at the present time almost universally take note of the vast difference in the destructive effect of a live load and a dead load; but the Board of Trade entirely ignore this fact, and adopt the same limiting stress in a main girder, where the greater portion of the load may be dead, as in a cross girder, where it is practically all live, and where vibration is set up by every passing wheel. It is generally admitted—and the practice and experience of mechanical engineers confirm the conclusion—that metal of any class may be subject to a working stress twice as great under a dead as under a purely live load. Some engineers make a compromise and take the ratio at one and a half times. If this be done, and a factor of safety of three be adopted in the instance of a purely dead load, the admissible working stresses for iron having an ultimate strength of 20 tons per square inch would be $6\frac{2}{3}$ tons for a dead load, $5\frac{1}{2}$ tons for half dead and half live, 5 tons for quarter dead and three-quarters live (which is about the proportion obtaining in railway girders of 100 feet span), $4\frac{1}{3}$ tons for all live load, and $2\frac{1}{3}$ tons for members subject to alternate tension and compression of equal intensity. With steel having a strength of

30 tons, the corresponding stresses would be 50 per cent. greater—that is to say, they would range from $6\frac{2}{3}$ tons for an all live load to 10 tons for an all dead load. If the stresses be limited as above, the results of experiment and of actual practice show that a structure may be subject to an indefinite number of repetitions of the stress without injury. But, in the case of hurricanes, the repetitions will necessarily be few and far between, and higher stresses are therefore admissible in the members of wind-bracing than in the piston-rod of a steam engine, though both are subject to alternate tensile and compressive stresses. When it is remembered that the dead weight between the piers of the 1,700-feet span is upwards of 10,000 tons, whilst the live load due to a couple of heavy coal trains would be less than one-tenth of that amount, the relative lowness of the $7\frac{1}{2}$ tons per square inch maximum stress in the Forth Bridge girders, under the combined action of an impossible load and an improbable hurricane, will be conceded by all.

So far as the author is aware—although it has been established beyond all dispute that repeated application of a tensile stress amounting to two-thirds of the ultimate strength of the material would in time cause fracture—it has never been proved that the same conclusion applies to metal in compression. In fact, some of the author's experiments lead him to think that a contrary result might obtain. For example, one of the consequences of heavy varying stresses and vibrations is that the quality of the metal deteriorates, both iron and steel becoming more crystalline and less ductile. These conditions are rather favourable than otherwise to the resistance of a compression member. Thus the author tested some columns, 30 diameters in length, of high-class ductile steel, and of inferior crystalline steel, both having, however, the same tensile strength. The inferior steel bore 40 per cent. more load than the high-class steel, and it appears not improbable that, if the quality of the latter had been deteriorated by vibration and heavy stresses the ultimate resistance would have been increased as regards compressive stresses almost as much as it would be diminished in respect of tensile stresses. Similarly, in columns of the same proportion, the commonest class of pig iron would beat the finest brands of wrought iron.

Long struts were avoided at any expense by some engineers, but, the author thought, without good reason. The tubular struts in the Forth Bridge, if made of iron, would resist as high a compressive stress per square inch as the top flange of any existing girder, and the same remark would apply to steel. An interesting series of experiments was recently made in America with full-sized wrought iron hollow columns, from 8 inches to 12 inches in diameter, and up to 28 feet in length. The influence of the length of the column on its resistance was singularly small. For instance, the 8-inch column, when 15 diameters in length, failed with a stress of 16·2 tons per square inch; and when as much as 42 diameters in length, with 15·6 tons. Now the model of the Britannia Bridge, 75 feet in span, failed with 14·8 tons per square inch compression; Brunel's 66-feet girder, having a 3-feet wide cellular top member, failed with 12·6 tons; and some girders tested by the author with 15 tons per square inch as an average on the top flange.

Taking the mean results of a large number of experiments, the influence of length between the practical limits of 15 to 25 diameters would be just appreciable; but, if only a few experiments were compared, the deduction might be drawn that lengthening a column, or rounding its

ends, increased rather than reduced its strength. Thus one steel tube, 20 diameters in length, tested by the author, bore 22 tons per square inch, whilst a similar tube of half the length bore only 19·2 tons. Again, a round-ended column, 20 diameters in length, bore 19·3 tons per square inch, whilst a flat-ended one failed with ·18 tons. No doubt greater regularity would obtain with full-sized than with model tubes, but still the practical fact remained that, within the limits occurring in the Forth Bridge, the compressive resistance of the tubular struts would be as high as that of the top flange of any plate or box girder that could be built, and that whatever stress was admissible in the girder would be admissible in the struts. This was a reassuring result to arrive at, because the practical experience had been chiefly with girders, and not with tubular struts.

The author's experiments conclusively prove that steel is far superior to iron as a material for struts, though the superiority is not so great as when tension members are in question. Thus the Forth Bridge struts will be from 30 to 40 per cent. stronger in steel than in iron, whilst the tension members will be about 50 per cent. stronger. It does not follow that the steel strut would not be 50 per cent. better also as regards actual work, which is very different to what takes place in a testing machine. A steel or an iron rail, tested for transverse strength in a machine, will, as a rule, bend many inches, and fail by distortion of the head under the compressive stress. In actual work hundreds of such rails break, but it is the tensile and not the compressive stress which causes the failure, and there is no distortion of the head as in the testing machine. Similarly, when riveted girders break under traffic, it is not the top flanges with a calculated stress on the average of about one-third of the ultimate resistance that give way, but the bottom members, where the calculated stress is only about one-fourth of the ultimate resistance. In short, the universal experience is that fatigue is far more injurious to iron or steel under tensile than under compressive stress, and it follows that the factor of safety should not be the same in the two cases. This is quite consistent with ordinary practice, for probably the majority of girder bridges in this country have equal-sized top and bottom flanges, which, after allowing for the riveting, would give a factor of about three for the compression and about four for the tension members respectively.

The peculiarities of steel are tolerably well understood now, and amongst other precautions it is especially desirable to so design the joints in tension that no tearing action shall be set up along a line of rivet-holes. Accidents of workmanship necessitate the provision of a good factor of safety in steel joints in tension; but, after watching the testing of many steel tubes under compression, the author cannot conceive any accident of workmanship which could bring about the failure of steel tubes such as those in the Forth Bridge, even if the working stress was raised to two-thirds, instead of about one-fourth, of the ultimate resistance. In fine, he believes a steel tube to be the most trustworthy member which could be introduced into a great and unprecedented work.

As regards cost of manufacture, the difference is comparatively small between a circular and a rectangular member. The main tubes will be made up circumferentially of ten bent plates, lap-jointed and double-riveted through the flanges of ten rolled beams, which will run longitudinally through the whole length of the tube. Stiffening rings will also be introduced at suitable intervals. The junctions of the tubular

struts with the tubular bottom members offered some little difficulty at first in designing, but this being surmounted, the manufacture of the junction lengths becomes, as it were, a piece of ship-builder's work, except that the ship-builder has to deal with far more complex curvatures than will be found in the junction lengths.

Before dismissing the question of steel in compression, the author would wish to mention the results of some experiments made by him on steel which had been previously subjected to end pressure in a tube, so that flexure could not occur. The rods were 1 inch diameter by 30 inches long. With the mildest steel, the resistance to flexure was 14·5 tons per square inch in the uncompressed rods, and 22 tons, or say 50 per cent. more, in the rods which had previously been subjected to an end pressure of 36 tons per square inch. With somewhat harder steel, the corresponding figures were 16 tons in the uncompressed, and from 26 to 29 tons in the previously compressed bars—a gain of from 60 to 80 per cent. The bars, when tested in tension, showed no loss in strength or elongation from the previous compression. As 30-ton steel, after the end pressure had been applied, bore as much load without flexure as 54-ton steel which had not been so treated, it is clear that the adoption of mild steel in railway bridges would be much accelerated if some simple practical method could be devised for bringing about the molecular change effected in the above instances by an end pressure.

It has been stated that the maximum wind-pressure upon the 1,700-feet span has been assumed to be equivalent to a pressure of 56 lbs. per square foot upon double the superficial area of the girder. It is to be regretted that this assumption necessarily involves many matters of pure conjecture. For example, though a wind-pressure of 56 lbs. has undoubtedly been registered by anemometers exposing a surface of a couple of square feet, it has never been proved to prevail instantaneously over so great a width as the 1,700-feet span. Again, the relative resistances offered by the windward and leeward girders of a bridge have not been measured, and still less has any experimental approximation been obtained to the resistance of an entire bridge with its floor and cross-bracing. Probably much may be done by models, and the author intends to so ascertain, if possible, the probable resistance of the Forth Bridge expressed in square feet of flat surface. Experiments with relation to wind-pressure have been commenced at the site of the bridge—a pressure board, 20 feet long and 15 feet wide, having been fixed on the top of a tower on the island of Inchgarvie, where the central pier of the bridge will be placed. The apparatus is adapted to test the relative resistances offered by different surfaces, and during the progress of the works it is hoped many now open questions may be settled. The experiments will probably not affect in any way the design of the bridge, because the leading features of the design and the working stresses and wind-pressure to be provided for have long since been settled with the Board of Trade. Until the experiments are complete, however, it will be impossible to state with precision what factor of safety will belong to the work, though it is possible to state, without reservation of any kind, that in any event the Forth Bridge, as designed, will be relatively stronger than any other bridge yet constructed. Owing to the large dead weight and the spread of the girders at the piers, a wind-pressure equivalent to 2 cwt. per square foot upon the surface of one girder would be required to overturn the bridge, assuming it not to be held down by bolts. The holding-down

bolts provided, however, about double the resistance to overturning, so that 4 cwt. of wind-pressure per square foot upon the single surface would be required to upset the bridge; and under this ideal pressure, though the wind-bracing would, it is true, be on the point of failing, none of the great tubes or tension members of the main girders would even be permanently deformed.

Changes of temperature as well as gales of wind will affect the stresses upon the steel but to a comparatively insignificant extent. In designing a certain class of work, nothing embarrasses an engineer more than questions arising out of the expansion and contraction of materials. An experienced engineer will know that in certain instances he may entirely ignore the influence of temperature, whilst in others it is all-important. For example, if a provision were not made in the case of point rods, the points would fail to close, and great loss of life might follow the consequent derailment of a train, whilst, on the other hand, infinite complication would result if a similar provision had to be made in a structure like the Crystal Palace, or in long station roofs, or in girders carrying buildings. Only experience could decide whether it would be safe to carry an ornamental ashlar-faced building on a girder 150 feet in length without running the risk of inducing cracks in the masonry; but the author, having tried it, can say that the effects of temperature in such a case may be safely ignored. Similarly he had used, without inconvenience, girders 630 feet in length in the floor of a building, and purlines of equal length in the roof of a station. Each case must, however, be dealt with on its own merits; for in another instance, where a gasworks roof had fallen down like a pack of cards, he had traced the cause of the accident unmistakably to the expansion of the iron slate-battens, which were exposed to exceptionally high temperatures at times. An engineer is apt to consider he has taken sufficient account of expansion if he adopts the conventional course of placing one end of his girders on rollers or sliding plates, so that the bridge may be free to expand in the direction of its length. The superstructure, it is true, may be twice as wide as it is long, but it must take its chance as regards expansion in the direction of the width. Arched station-roofs, such as the St. Pancras roof of 240-feet span and 700 feet length, seem to require no provision for expansion in either direction. Again, the Victoria Bridge at Pimlico has longitudinal girders 913 feet in length, and cross girders 100 feet in length, with no provision for expansion in either direction. On the other hand, at the Southwark Bridge, grooves had to be cut in the masonry to admit of the free expansion of the cast-iron spandrils, which had been fractured by expansion in several instances, though the arch was only 240 feet in span, and the spandrils were not continuous across the piers. However much the engineer may desire to eliminate stresses due to expansion, he will find it impossible to do so, for the very obvious reason that the temperature is not uniform at any instant, and that even in this climate there may be a difference of 50 degrees between the temperature in the sun and in the shade. Take the case of an ordinary lattice girder with trough-shaped top and bottom members and double lattices. One side plate of the trough may be highly heated by the direct rays of the sun, and the other be completely in the cool shade, and one tie bar may similarly differ from its companion bar in temperature. If the girder were free to warp in any direction like a thin plank, little stress would result; but as it is not free to adapt itself to the un-

equal heating, stresses of considerable severity must occur, since 12° increase of temperature is the equivalent as regards elongation of 1 ton per square inch stress. On a hot sunny day the Britannia tube was found to warp 3 inches laterally and $2\frac{1}{2}$ inches vertically when free to move; and, clearly, if such tendency be restrained, uniformity of stress is unattainable. The Forth Bridge tubular struts would similarly tend to curve under the action of the sun's rays, but, being braced together, they will not be free to do so, and stress must result. Every structure, in fact, is subject to such stresses, which are one of the things covered by the usual factor of safety. Stone buildings and arches are no exception to the rule; indeed, the author, from instances which have come under his own knowledge, is satisfied that the stresses due to changes of temperature are often relatively far more severe in stone than in iron arches.

Since by no practical means could stresses from expansion and contraction be wholly eliminated from the Forth Bridge, it became a matter for careful consideration what provision for expansion would be requisite or expedient, and what could be dispensed with. There could be no doubt, of course, that longitudinal expansion in the 1,700-feet span should be provided for by placing one end of the 350-feet girder on rollers where it was supported by the cantilever. The direct stresses would thus be eliminated, but there remained those due to the unequal heating of the different members, as in every other bridge. These stresses were not included in the estimated maximum tension and compression per square inch given in a previous part of this paper, but were assumed, as usual, to be covered by the factor of safety. A more difficult question arose with reference to the portions of the girders between the piers. Thus the Inchgarvie pier consists of four cylindrical masses of masonry, spaced 270 feet apart longitudinally, and 120 feet apart transversely, centre to centre. The point to be decided was whether the great girders should be bolted to each mass of masonry, or be fixed at one end only of the above 270 feet, and be placed on rollers at the other end. This would be done, as a matter of course, with an ordinary 270-feet span girder bridge, but the conditions here were very different. In the first place, the pressure was enormous, and a bed-plate 35 feet by 18 feet was not a convenient one to provide with rollers. The most important point, however, was that sudden and unequally distributed gusts of wind caused stresses, which rendered it extremely desirable to dispense with rollers if possible. On considering the question in detail, it proved to be quite possible to do so. The range of temperature in this climate is not really great on well-protected surfaces, as the practical uniformity of temperature a few inches below the ground testifies. Taking the average of twenty years' observations at Greenwich, the mean shade temperature of the different months ranged from 38·94° in January to 62·54° in July. As the average for the whole twenty years was 49·69°, the range was thus merely 11° below and 13° above the mean temperature. Since 12° corresponds to a ton per square inch stress, ironwork bedded at a mean temperature in a mass of masonry might well be subject to no greater stress from variation of temperature than plus and minus 1 ton per square inch, which is far less than would obtain in a so-styled free-to-expand structure exposed to the rays of the sun.

Last year was characterised by great extremes of temperature. In January the temperature fell to 12·7°, whilst in July it rose to 97·1°, a range of no less than 84·4° in the shade. The lowest mean daily temperature was 19·4° in January, and the highest 78·6° in July—a range of

59·2°. The maximum daily range was 37°, and monthly range 53°, both in July. In the sun the temperature rose as high as 150°, so the extreme range for the year would be no less than 137°. The average yearly range being less than 24°, a clear explanation is thus afforded of the fact so well proved by experience, that provision for expansion is essential in point rods, signal wires, and similar exposed and light pieces of ironwork, whilst it may safely be ignored in the case of girders enclosed in buildings or bedded in jack-arches.

Having reference to the considerations thus briefly set forth, and to the behaviour of existing structures of all classes in this climate, it proved, on investigation, to be quite unnecessary, as far as temperature was concerned, to provide rollers at Inchgarvie pier. The steel tubes between the four cylindrical masses of masonry will be covered, like marine boilers, with a couple of inches of 'fossil meal' or some other suitable non-conducting material, and an exterior iron envelope. Inside the tubes will be lined with about 2 feet in thickness of cement concrete, to serve as an equaliser of temperature, and, these precautions being taken, the results of calculation show that the stresses from changes of temperature will be of no moment either to the superstructure or to the masonry.

There still remained the question whether, for other reasons than temperature, rollers might not be necessary at Inchgarvie. Since the 270-feet-long tubes would be erected upon scaffolding, there would be no stress upon the metal at first, but as the erection of the cantilevers by overhanging proceeded, there would be the gradually increasing thrust from the bottom member, and it appeared difficult to say whether this thrust would come upon the tubes or upon the piers as abutments, unless rollers were introduced. A compressive stress of 5 tons per square inch would shorten the tube $1\frac{1}{2}$ inches, and as the stout masonry piers would tilt very little, this movement could not occur, and the tubes would not take up their share of the work unless some sliding were provided for. After a careful consideration of all the conditions of the problem, including changes of temperature, the author came to the conclusion that a certain amount of initial stress on the tubes between the masonry piers was desirable; and although it might at first appear to be difficult to do this with a tube 12 feet in diameter by 2 inches in thickness, the difficulty vanished, as usual, upon being grappled with. He proposed simply to make the upper and lower bed-plates, which were intended to slide on each other during the erection of the bridge, with serrated surfaces sloping at an angle of 1 in 6. As the coefficient of the well-greased and planed steel surfaces would not exceed one-twentieth of the load, the shortening of the tube under the compressive stress due to the erection of the cantilevers would proceed freely, whilst the desired initial stress would be put on partly by the weight of the structure and the tightening of the holding-down bolts taking effect on the 1 in 6 incline, and partly by the test load of the bridge. A movement of $1\frac{1}{2}$ inches would be provided for temporarily, and the two bed-plates would finally be gripped together and made fast to the piers by 40 holding-down bolts of 3 inches diameter. When complete, the stresses on the metal would never exceed the limit of $7\frac{1}{2}$ tons under the joint influence of live load, wind, and temperature, and the pressure upon the masonry piers and foundations would be well within the working limits.

It is unnecessary to refer in detail to the mode of erection, as it is obvious that the work will be commenced at each pier, and be proceeded with by

adding successive portions to the ends of the cantilevers until the same are complete. The central girders will also probably be erected on the overhanging system, temporary connections being formed between the ends of the cantilevers and the central girders. The closing lengths or key-pieces at the centre of each 1,700-feet span will be put in on a cloudy day, when there is little variation in temperature, and the details will be so arranged that the key-piece can be completed and the temporary connections cut away in a few hours, so as to avoid any temporary inconvenience from expansion and contraction.

No special difficulty will arise with respect to the foundations, though the works will be, of course, on an unusually large scale. The island of Inchgarvie is of trap rock, and the central pier at that spot will consist of four cylindrical masses of concrete and rubble-work faced with granite, and having a diameter of 45 feet at the top and 70 feet at the bottom. The height above high water will be 18 feet, and the depth below the same will vary from 24 feet to 70 feet. After the sloping face of the rock foundation has been cut into steps, wrought-iron caissons will be floated out, lowered into place, and filled with concrete lowered through the water in hopper-bottomed skips. Queensferry Pier will be founded on boulder clay. Open-topped cylindrical caissons, 70 feet diameter, with an external and internal skin 7 ft. 6 in. apart, will be floated out and lowered into place. The space between the skins will be filled with concrete, to give strength and weight to overcome frictional resistance in sinking. Grab excavators will be carried on a turntable top to the caissons to remove the earth from the interior, and pneumatic apparatus will be supplied to enable men to clear boulders from the cutting edge of the caissons. From a depth of 6 feet below low water upwards, the masonry will be built in the dry, inside a movable caisson connected by an indiarubber joint with the permanent caisson below it. The piers will be carried down at least 10 feet into the boulder clay, which will give depths ranging from 68 feet to 88 feet below high water and 18 feet less at low water in the respective cylinders. In round numbers the weight of one of the cylindrical piers at Queensferry may be taken at 16,000 tons, and the combined vertical pressure on the top of the pier from the dead weight of superstructure, rolling load, and wind pressure at 8,000 tons; so the load on the clay would average about 6 tons per square foot over the area of the foundation. This is an insignificant amount on such hard clay as that at the Forth, and the margin is ample, therefore, to allow of the unequal distribution of the pressure due to the action of partial blasts of wind and of a certain amount of expansion in the tubes connecting the piers.

The total length of the great continuous girder is 5,330 feet, or say a mile, and of the viaduct approaches 2,754 feet, or rather over half a mile. There is nothing calling for special remark in the viaduct. The piers will be of rubble masonry, faced with granite, and the superstructure of iron lattice girders with buckled plate floor and trough rail bearers, as in the instance of the main spans. The main girders, spaced 16 feet apart, will be placed under the railway, and there will be a strong parapet and wind screen to protect the trains.

To engineers little need be said respecting the stiffness of a girder bridge having the proportions adopted in the present case. The central girder has a depth of one-seventh of the span, whilst the cantilevers may be looked upon as halves of a girder having a depth of one-fourth of the span. Exceptional depths like these confer exceptional stiffness, and there

is the additional fact that the live load of a passing train will be quite insignificant as compared with the dead load of the structure. The heaviest train traversing the bridge will not deflect the 1,700-feet girder more than 4 inches, which is considerably less than the deflection of the 460-feet span of Saltash Bridge under its test load, whilst a wind pressure, equivalent to 30 lbs. per square foot over the entire 1,700 feet, would bend the bridge laterally less than 9 inches.

About 42,000 tons of steel will be used in the superstructure of the main spans, and 3,000 tons of wrought iron in that of the viaduct approach. The total quantity of masonry in the piers and foundations will be about 125,000 cubic yards, and the estimated cost of the entire work, upon the basis of the prices at which the original suspension bridge was contracted for is about 1,500,000*l*. Owing to the varying price of steel, and to the magnitude and novelty of the undertaking, this estimate must be taken as approximate only, as a contract has not yet been concluded for the works.

It will be gathered from the preceding necessarily brief and incomplete description of the proposed Forth Bridge that no novel or untried elements enter into the design. In principle, a continuous girder is as old a type of construction as an arch or a suspension bridge; and probably, in prehistoric times, streams were crossed by the aid of a couple of overhanging branches and an intermediate central portion, constituting a structure rude in appearance but identical in principle with the girder bridge. The merit of the design, if any, will be found, not in the novelty of the principles underlying it, but in the resolute application of well-tested mechanical laws and experimental results to the somewhat difficult problem offered by the construction of so large a bridge across so exposed an estuary as the Firth of Forth.

TRANSACTIONS OF THE SECTIONS.

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Section A.—MATHEMATICAL AND PHYSICAL SCIENCE.

President of the Section—
The Right Hon. Professor Lord Rayleigh, M.A., F.R.S., F.R.A.S., F.R.G.S.

THURSDAY, AUGUST 24.

The President delivered the following Address:—

In common with some of my predecessors in this chair, I recognise that probably the most useful form which a presidential address could take, would be a summary of the progress of physics, or of some important branch of physics, during recent years. But the difficulties of such a task are considerable, and I do not feel myself equal to grappling with them. The few remarks which I have to offer are of a general, I fear it may be thought of a commonplace, character. All I can hope is that they may have the effect of leading us into a frame of mind suitable for the work that lies before us.

The diversity of the subjects which come under our notice in this section, as well as of the methods by which alone they can be adequately dealt with, although a sign of the importance of our work, is a source of considerable difficulty in the conduct of it. From the almost inevitable specialisation of modern science, it has come about that much that is familiar to one member of our Section is unintelligible to another, and that details whose importance is obvious to the one fail altogether to rouse any interest in the mind of the other. I must appeal to the authors of papers to bear this difficulty in mind, and to confine within moderate limits their discussion of points of less general interest.

Even within the limits of those departments whose foundation is evidently experimental, there is room, and indeed necessity, for great variety of treatment. One class of investigators relies mainly upon reiterated appeals to experiment to resolve the questions which appear still to be open; while another prefers, with Thomas Young, to base its decisions as far as possible upon deductions from experiments already made by others. It is scarcely necessary to say that in the present state of science both methods are indispensable. Even where we may fairly suppose that the fundamental principles are well-established, careful and often troublesome work is necessary to determine with accuracy the constants which enter into the expression of natural laws. In many cases the accuracy desirable, even from a practical point of view, is hard to attain. In many others, where the interest is mainly theoretical, we cannot afford to neglect the confirmations which our views may derive from the comparison of measurements made in different fields and in face of different experimental difficulties. Examples of the inter-dependence of measurements apparently distinct will occur to every physicist. I may mention the absolute determinations of electrical resistance, and of the amounts of heat developed from electrical and mechanical work, any two of which involve also the third, and the relation of the velocity of sound to the mechanical and thermal properties of air.

Where a measurement is isolated, and not likely to lead to the solution of any open question, it is doubtless possible to spend upon it time and attention that might with advantage be otherwise bestowed. In such a case we may properly be

satisfied for a time with work of a less severe and accurate character, knowing that with the progress of knowledge the way is sure to be smoothed both by a better appreciation of the difficulties involved, and by the invention of improved experimental appliances. I hope I shall not be misunderstood as underrating the importance of great accuracy in its proper place if I express the opinion that the desire for it has sometimes had a prejudicial effect. In cases where a rough result would have sufficed for all immediate purposes, no measurement at all has been attempted, because the circumstances rendered it unlikely that a high standard of precision could be attained. Whether our aim be more or less ambitious, it is important to recognise the limitations to which our methods are necessarily subject, and as far as possible to estimate the extent to which our results are uncertain. The comparison of estimates of uncertainty made before and after the execution of a set of measurements may sometimes be humiliating, but it is always instructive.

Even when our results show no greater discrepancies than we were originally prepared for, it is well to err on the side of modesty in estimating their trustworthiness. The history of science teaches only too plainly the lesson that no single method is absolutely to be relied upon, that sources of error lurk where they are least expected, and that they may escape the notice of the most experienced and conscientious worker. It is only by the concurrence of evidence of various kinds and from various sources that practical certainty may at last be attained, and complete confidence justified. Perhaps I may be allowed to illustrate my meaning by reference to a subject which has engaged a good deal of my attention for the last two years—the absolute measurement of electrical resistance. The unit commonly employed in this country is founded upon experiments made about twenty years ago by a distinguished committee of this Association, and was intended to represent an absolute resistance of 10^9. C.G.S., *i.e.* one ohm. The method employed by the committee at the recommendation of Sir W. Thomson (it had been originally proposed by Weber) consisted in observing the deflection from the magnetic meridian of a needle suspended at the centre of a coil of insulated wire, which formed a closed circuit, and was made to revolve with uniform and known speed about a vertical axis. From the speed and deflection in combination with the mean radius of the coil and the number of its turns, the absolute resistance of the coil, and thence of any other standard, can be determined.

About ten years later Kohlrausch attacked the problem by another method, which it would take too long to explain, and arrived at the result that the B.A. unit was equal to 1·02 ohms—about two per cent. too large. Rowland, in America, by a comparison between the steady battery current flowing in a primary coil with the transient current developed in a secondary coil when the primary current is reversed, found that the B.A. unit was ·991 ohms. Lorentz, using a different method again, found ·980, while H. Weber, from distinct experiments, arrived at the conclusion that the B.A. unit was correct. It will be seen that the results obtained by these highly competent observers range over about four per cent. Two new determinations have lately been made in the Cavendish laboratory at Cambridge, one by myself with the method of the revolving coil, and another by Mr. Glazebrook, who used a modification of the method followed by Rowland, with the result that the B.A. unit is ·986 ohms. I am now engaged upon a third determination, using a method which is a modification of that of Lorentz.

In another important part of the field of experimental science, where the subject-matter is ill understood, and the work is qualitative rather than quantitative, success depends more directly upon sagacity and genius. It must be admitted that much labour spent in this kind of work is ill directed. Bulky records of crude and uninterpreted observations are not science, nor even in many cases the raw material out of which science will be constructed. The door of experiment stands always open; and when the question is ripe, and the man is found, he will nine times out of ten find it necessary to go through the work again. Observations made by the way, and under unfavourable conditions, may often give rise to valuable suggestions, but these must be tested by experiment, in which the conditions are simplified to the utmost, before they can lay claim to acceptance.

When an unexpected effect is observed, the question will arise whether or not an explanation can be found upon admitted principles. Sometimes the answer can be quickly given; but more often it will happen that an assertion of what *ought* to have been expected can only be made as the result of an elaborate discussion of the circumstances of the case, and this discussion must generally be mathematical in its spirit, if not in its form. In repeating, at the beginning of the century, the well-known experiment of the inaudibility of a bell rung in vacuo, Leslie made the interesting observation that the presence of hydrogen was inimical to the production of sound, so that not merely was the sound less in hydrogen than in air of equal pressure, but that the actual addition of hydrogen to rarefied air caused a diminution in the intensity of sound. How is this remarkable fact to be explained? Does it prove that, as Herschel was inclined to think, a mixture of gases of widely different densities differs in its acoustical properties from a single gas? These questions could scarcely be answered satisfactorily but by a mathematical investigation of the process by which vibrations are communicated from a vibrating solid body to the surrounding gas. Such an investigation, founded exclusively upon principles well established before the date of Leslie's observation, was undertaken years afterwards by Stokes, who proved that what Leslie observed was exactly what ought to have been expected. The addition of hydrogen to attenuated air increases the wave-length of vibrations of given pitch, and consequently the facility with which the gas can pass round the edge of the bell from the advancing to the retreating face, and thus escape those rarefactions and condensations which are essential to the formation of a complete sound-wave. There remains no reason for supposing that the phenomenon depends upon any other elements than the density and pressure of the gaseous atmosphere, and a direct trial, *e.g.* a comparison between air and a mixture of carbonic anhydride and hydrogen of like density, is almost superfluous.

Examples such as this, which might be multiplied *ad libitum*, show how difficult it often is for an experimenter rightly to interpret his results without the aid of mathematics. It is eminently desirable that the experimenter himself should be in a position to make the calculations, to which his work gives occasion, and from which in return he would often receive valuable hints for further experiment. I should like to see a course of mathematical instruction arranged with especial reference to physics, within which those whose bent was plainly towards experiment might, more or less completely, confine themselves. Probably a year spent judiciously on such a course would do more to qualify the student for actual work than two or three years of the usual mathematical curriculum. On the other side, it must be remembered that the human mind is limited, and that few can carry the weight of a complete mathematical armament without some repression of their energies in other directions. With many of us difficulty of remembering, if not want of time for acquiring, would impose an early limit. Here, as elsewhere, the natural advantages of a division of labour will assert themselves. Innate dexterity and facility in contrivance, backed by unflinching perseverance, may often conduct to successful discovery or invention a man who has little taste for speculation; and on the other hand the mathematician, endowed with genius and insight, may find a sufficient field for his energies in interpreting and systematising the work of others.

The different habits of mind of the two schools of physicists sometimes lead them to the adoption of antagonistic views on doubtful and difficult questions. The tendency of the purely experimental school is to rely almost exclusively upon direct evidence, even when it is obviously imperfect, and to disregard arguments which they stigmatise as theoretical. The tendency of the mathematician is to overrate the solidity of his theoretical structures, and to forget the narrowness of the experimental foundation upon which many of them rest.

By direct observation, one of the most experienced and successful experimenters of the last generation convinced himself that light of definite refrangibility was capable of further analysis by absorption. It has happened to myself, in the course of measurements of the absorbing power of various media for the different rays of the spectrum, to come across appearances at first sight strongly confirmatory of Brewster's views, and I can therefore understand the persistency with which he

retained his opinion. But the possibility of further analysis of light of definite refrangibility (except by polarisation) is almost irreconcilable with the wave theory, which on the strongest grounds had been already accepted by most of Brewster's contemporaries; and in consequence his results, though urgently pressed, failed to convince the scientific world. Further experiment has fully justified this scepticism, and in the hands of Airy, Helmholtz, and others, has shown that the phenomena by which Brewster was misled can be explained by the unrecognised intrusion of diffused light. The anomalies disappear when sufficient precaution is taken that the refrangibility of the light observed shall really be definite.

On similar grounds undulationists early arrived at the conviction that physically light and invisible radiant heat are both vibrations of the same kind, differing merely in wave-length; but this view appears to have been accepted slowly, and almost reluctantly, by the experimental school.

When the facts which appear to conflict with theory are well-defined and lend themselves easily to experiment and repetition, there ought to be no great delay in arriving at a judgment. Either the theory is upset, or the observations, if not altogether faulty, are found susceptible of another interpretation. The difficulty is greatest when the necessary conditions are uncertain, and their fulfilment rare and uncontrollable. In many such cases an attitude of reserve, in expectation of further evidence, is the only wise one. Premature judgments err perhaps as much on one side as on the other. Certainly in the past many extraordinary observations have met with an excessive incredulity. I may instance the fire-balls which sometimes occur during violent thunderstorms. When the telephone was first invented, the early reports of its performances were discredited by many on quite insufficient grounds.

It would be interesting, but too difficult and delicate a task, to enumerate and examine the various important questions which remain still undecided from the opposition of direct and indirect evidence. Merely as illustrations I will mention one or two in which I happen to have been interested. It has been sought to remedy the inconvenience caused by excessive reverberation of sound in cathedrals and other large unfurnished buildings by stretching wires overhead from one wall to another. In some cases no difference has been perceived, but in others it is thought that advantage has been gained. From a theoretical point of view it is difficult to believe that the wires could be of service. It is known that the vibrations of a wire do not communicate themselves in any appreciable degree directly to the air, but require the intervention of a sounding-board, from which we may infer that vibrations in the air would not readily communicate themselves to stretched wires. It seems more likely that the advantage supposed to have been gained in a few cases is imaginary than that the wires should really have played the part attributed to them.

The other subject on which, though with diffidence, I should like to make a remark or two, is that of Prout's law, according to which the atomic weights of the elements, or at any rate of many of them, stand in simple relation to that of hydrogen. Some chemists have reprobated strongly the importation of *à priori* views into the consideration of the question, and maintain that the only numbers worthy of recognition are the immediate results of experiment. Others, more impressed by the argument that the close approximations to simple numbers cannot be merely fortuitous, and more alive to the inevitable imperfections of our measurements, consider that the experimental evidence against the simple numbers is of a very slender character, balanced, if not outweighed, by the *à priori* argument in favour of simplicity. The subject is eminently one for further experiment; and as it is now engaging the attention of chemists, we may look forward to the settlement of the question by the present generation. The time has perhaps come when a re-determination of the densities of the principal gases may be desirable—an undertaking for which I have made some preparations.

If there is any truth in the views that I have been endeavouring to impress, our meetings in this Section are amply justified. If the progress of science demands the comparison of evidence drawn from different sources, and fully appreciated only by minds of different orders, what may we not gain from the opportunities here given

for public discussion, and, perhaps more valuable still, private interchange of opinion? Let us endeavour, one and all, to turn them to the best account.

The following Reports and Papers were read:—

1. *Second Report of the Committee for the Measurement of the Lunar Disturbance of Gravity.*—See Reports, p. 95.

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2. *Report of the Committee upon the present state of our Knowledge of Spectrum Analysis.*—See Reports, p. 120.

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3. *On the Tension of Mercury Vapours at Common Temperatures.* By Professor LORD RAYLEIGH, *F.R.S.*

The author called attention to the difficulty of reconciling the values of Regnault and Hagen with the phenomena observed by Crookes relating to the viscosity of gases at high exhaustions. The total gaseous pressure in the working chamber cannot be less than that of the mercury at the pump. If the penetration of mercury vapour be prevented by chemical means, some other gas must be present in equivalent quantity. If the value of Regnault and Hagen is substantially correct, it does not appear how the phenomena could vary so much as they are observed to do at the highest degrees of exhaustion as measured by the Macleod gauge. The question then arises whether the value of mercury tension hitherto received may not be much in excess of the truth. In Hagen's researches it is assumed without reason that the pressure in a chamber of variable temperature is governed by the temperature of the coldest part, but this consideration tells in the wrong direction. It was suggested that possibly a change in the capillary constant, or currents in the fluid mercury at the chilled surface of the meniscus, might have had something to do with the minute changes of level which have been attributed to differences of pressure in the mercury vapour.

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4. *On the Velocity of White and Coloured Light.* *By* Professor G. FORBES, *M.A.*, *F.R.S.E.*

The author gave an account of the experiments made by him in conjunction with Dr. James Young, F.R.S., with a view to determining the velocity of light. This research has been published in the Transactions of the Royal Society. The chief point of interest is that it appears that the velocity of blue light is greater than that of red, the difference being between 1 and 2 per cent. of the whole velocity.

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5. *Preliminary Account of Results obtained during the late total Solar Eclipse* (*May* 17, 1882). *By* Dr. ARTHUR SCHUSTER, *F.R.S.*, *and* Captain ABNEY, *F.R.S.*

Three photographs of the corona were obtained with different exposures. The comet *Tewfik,* discovered during the eclipse, appears on the photographs, and the change in its position on successive plates shows that it was receding from the sun. A plate exposed in a camera, which had a prism in front of the lens, showed a series of impressions corresponding to the different kinds of light sent out by the prominences. It is seen from this that different prominences were at different temperatures. The most intense image in every case corresponds to the calcium lines.

A photograph obtained in a complete spectroscope gives a complicated prominence spectrum, a strong continuous spectrum in the lower parts of the corona, a reversal of the solar line G in the upper regions, and a great number of coronal lines in the blue, violet, and ultra-violet.

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6. *On some Matters relating to the Sun.* *By* Dr. ARTHUR SCHUSTER, *F.R.S.*

Observations of the shape assumed by the solar corona in successive eclipses during the last fifteen years have shown remarkable changes coincident with the sunspot period. The corona of sunspot minimum is characterised by a certain symmetry about an axis not far removed from the sun's axis of rotation, but very likely not quite coincident either with it or with an axis perpendicular to the plane of the ecliptic. Some apparent irregularities in the symmetry seem to be due to differences in the position of the earth in its annual orbit. Changes in the spectroscopic and polariscopic properties of the corona which are coincident and connected with the changes of form seem to point to a partly meteoric origin of the corona.

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7. *On the Method of Harmonic Analysis used in deducing the Numerical Values of the Tides of long period, and on a Misprint in the Tidal Report for* 1872. *By* G. H. DARWIN, *F.R.S.*—See Reports, p. 319.

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8. *On the Photographic Spectrum of Comet (Wells)* 1, 1882. *By* WILLIAM HUGGINS, *D.C.L., LL.D., F.R.S.*

[PLATE IX.]

Last year I had the honour of presenting to the British Association an account of a photograph of the spectrum of the brightest comet of that year, accompanied by some remarks on the unity of type of spectrum of all the comets to which the spectroscope had been applied since 1864.

The bright comet of the present year presents, for the first time, a spectrum differing essentially from the hydrocarbon type to which all the other comets belonged.

Observations of the visible region of the spectrum had already showed the probable absence of the usual hydrocarbon groups, one or two observers suspecting only the brightest of the groups. The comet gave a brilliant continuous spectrum, and also a bright double line coincident with that of sodium at D of the spectrum, and some other bright lines.

On May 31, I obtained a photograph of the spectrum of this comet. The plate was exposed for one hour and a quarter. Through the second half of the slit I took on the same plate a spectrum of *a* Ursa majoris for the determination in position of the lines of the comet's spectrum.

The photographic plate showed a strong continuous spectrum extending from about F to a little beyond H.

In the continuous spectrum of the comet of last year the Fraunhofer lines were clearly visible, but in the stronger continuous spectrum of the present comet, I was not able to distinguish any of these solar lines.

The slit was indeed more open than was the case last year, and this circumstance would make these lines less distinct, but the lines G and H are well seen in the star's spectrum taken under the same conditions. We may conclude therefore that the part of the comet's original light which gives a continuous spectrum is much stronger relatively to the reflected solar light in this comet than was the case in the comet of last year, and for this reason the Fraunhofer lines are not to be seen.

In agreement with eye observations made in the visible region, this photograph does not contain the strong ultra-violet group assigned to cyanogen; also the bright groups of the comet of last year between G and *h*, and between *h* and H do not appear to be present.

In the continuous spectrum at least five places of greater brightness can be distinguished, which undoubtedly represent groups of bright lines, though they are not sufficiently distinct in the photograph to admit of resolution into lines. The correctness of this interpretation is rendered much more probable by the circumstance that these groups, as is shown in the diagram, project beyond the strong con-

tinuous spectrum on one side. The head of the comet was in sharp focus upon the slit, and the continuous spectrum with defined edges corresponds to the nucleus, which in this comet was very distinct. The side of the spectrum on which these suspected groups project corresponds to the light of the corona on the side of the nucleus next the sun. We learn, therefore, that the light of this part of the coma consisted chiefly, in this region of the spectrum, of these groups; as, on the plate, only a very faint continuous spectrum can be seen between these projected parts of the bright spaces.

It is not possible to measure with accuracy the beginnings and endings of these groups. Measures as accurate as the circumstances would permit have been taken, therefore, of the brightest parts of the groups. The wave-lengths of these brightest parts are:—

λ 4253
,, 4412
,, 4507
,, 4634
,, 4769

As the lines of sodium were strong in the visible part, it may be that some of the light producing some of these groups may be due to that substance.

Mr. Hind has kindly furnished me with the distance of this comet from the sun at the time the photograph was taken. The comet was then 42,380,000 miles from the sun, while the comet of last year was distant 69,420,000 when I obtained the photograph of its spectrum. Considering the fact that the presence of sodium and the absence of the hydrocarbon groups were observed some time previously to the taking of the photograph, when the comet was much farther from the sun, we cannot attribute this difference of spectrum directly to greater heat through a nearer approach to the sun, but must regard it as arising from a different chemical constitution of the cometary stuff. Professor A. Herschel and Dr. von Konkoly showed long ago that the spectra of the periodic meteors are different for different swarms, and it is not surprising that the nuclei of comets should differ chemically.

If the light of comets is due to electric discharges, then, although these discharges would owe their existence to solar heat, their heating effect upon the cometary matter might not be strictly proportional to the nearness of the comet to the sun. In this case too the absence of the hydrocarbon lines might not necessarily indicate the freedom of the cometary matter from these substances. It has long been known how preferential is an electric discharge when several substances are present at the same time, and Dr. Hasselberg has recently shown by some laboratory experiments that in the presence of sodium vapour the hydrocarbon spectrum fades out. Notwithstanding these considerations, it is probable that the comet of this year owed the exceptional character of its spectrum to some unusual chemical condition of the meteoric matter which forms its nucleus.

[P.S.]—November 14.—The spectrum of the great comet which was discovered near the sun in September was similar in the visible region to that of comet Wells. Now that this comet has receded from the sun the lines of sodium are fainter, and the hydrocarbon groups seen in former comets have made their appearance. These observations support the view taken in this paper, but suggest that the chemical state of the matter of these two comets is not essentially different from that of former comets, but is probably a modification of the same fundamental constitution.—W. H.]

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9. *On the Photographic Spectrum of the Great Nebula in Orion.* *By* William Huggins, *D.C.L., LL.D., F.R.S.*

[Plate X.]

In September 1864 [1] I had the honour to announce to the Royal Society that I had discovered that certain of the Nebulæ (up to that time, eight in number), give a spectrum of bright lines. In one nebula four bright lines were observed.

[1] *Phil. Trans.* 1864, p. 437.

In January 1865,[1] I found that the light of the Great Nebula of Orion is resolved into the same set of bright lines. Further observations on the spectrum of the nebula in Orion, and the spectra of other nebulæ, were made subsequently with more powerful apparatus.[2]

The result of these observations was to show that in the visible region, the spectrum of the Great Nebula in Orion consists of four bright lines, the positions of which are λ 5005, 4957, 4861, and 4340. The least refrangible line appeared, in the instrument used, to be coincident with the less refrangible component of the brightest double line of the spectrum of nitrogen. The third and fourth lines agreed in position with the lines β and γ of the hydrogen spectrum, with which they were compared directly in the spectroscope.

During the last few years I have made several attempts to extend our knowledge of the spectra of the nebulæ into the more refrangible region beyond the reach of the eye by means of photography. On March 7 last (1882), I succeeded in obtaining a photograph of the spectrum of the Great Nebula in Orion.

The apparatus was the same with which I had photographed the spectra of stars, and the spectrum of comet *b*, 1881. It consists essentially of a spectroscope furnished with a prism of Iceland spar, and lenses of quartz, placed so that the slit shall be in the principal focus of a metallic speculum 18 inches in diameter, and driven by an electrically controlled clock.

A gelatine plate was used very sensitive from about Fraunhofer's *b* of the spectrum, to a long distance in the ultra-violet.

The exposure was limited by the coming up of clouds to about 45 minutes. The opening of the slit was made wider than in my work on the stars. The slit was kept upon a bright part of the nebula near the trapezium in the 'Fish's mouth' of the nebula.

The photographic plate shows a spectrum of bright lines sufficiently distinct to admit of measurement; there is also present an exceedingly faint continuous spectrum.

In my eye-observations of the visible region of the spectrum, I was nearly always conscious of the presence of a faint continuous spectrum, but in no part of the nebula did this continuous spectrum become strong relatively to the bright lines, which were present throughout the whole extent of the nebula.

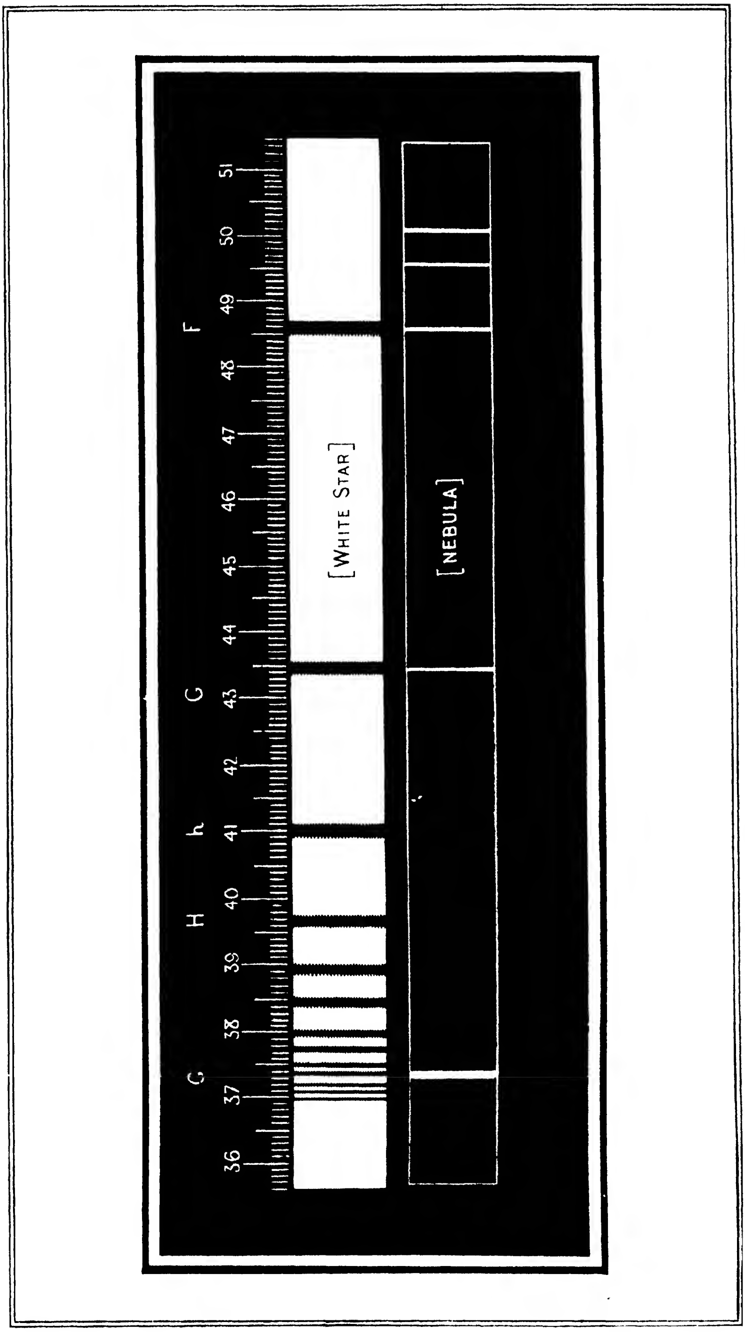
The great range of the spectrum to which the plate was sensitive enabled me to see upon it all the lines which had been previously observed with the eye. In addition to these known lines the plate shows a relatively strong line in the ultra-violet region, which is new to us.

As the slit was wide, this line appears broad on the plate, but for the same reason so do also the known lines. Eye-observations have shown these lines to be extremely narrow and defined at the edges. There is reason to believe that this new line, though relatively intense, is similar in character to the other lines, namely, narrow and defined. The great advantage of this control from lines common to the photographic plate and to observations by eye, is seen further in the following circumstance. The spaces occupied on the plate by the broad lines do not appear to be quite uniform, but somewhat less strong in the middle; but the results of the eye-observations show conclusively, as might be suspected for other reasons, that this appearance does not indicate duplicity of the lines, but simply a want of absolute precision of focal adjustment.

The broad character on the plate of this new line does not permit of quite the same accuracy of determination of position as would have been possible with a narrower slit. There is little doubt, however, that this new line agrees in position with the line ζ of the typical spectrum of the white stars.[3] For this reason, this typical spectrum has been placed in the diagram by the side of the photographic spectrum of the nebula. The wave-length of the new line is therefore λ 3730.

There can be little doubt that this typical spectrum is due to hydrogen, and

[1] *Proc. Roy. Soc.* vol. xiv. p. 39.
[2] *Phil. Trans.* 1868, p. 540, and *Proc. Roy. Soc.* vol. xx. p. 380.
[3] *Phil. Trans.* 1880, p. 672.



Illustrating Dr. W. Huggins' Paper On the Photographic Spectrum of the Great Nebula in Orion.

Spottiswoode & Co.

that this new line in the nebula, as well as the two less refrangible lines which had been observed by the eye, are produced by this substance.

It is of much interest to compare the extreme differences of character of these lines of hydrogen which are common to the white stars and to the nebula. In the stars these lines are very broad and winged at the edges, while in the nebula they are of exceeding thinness and wholly free from a winged condition, indicating great differences in the temperature and density of the gas as it exists in these two orders of celestial bodies.

I cannot say positively whether the lines of hydrogen between $H\gamma$ and the line ζ at 3730, which are present in the stars, are altogether absent in this nebula. If they exist in the spectrum of the nebula they must be exceedingly faint relatively to those present. I suspect a want of uniformity of the film at this part, and also beyond λ 3730, and this may indicate possibly the presence of very faint lines. Under the most favourable conditions of illumination, I am almost certain of faint lines at the positions of h and H. In the diagram only those lines about which there can be no uncertainty are inserted, and the new line is made broad for the purpose of indicating its great intensity relatively to the other lines.

In my laboratory experiments, I have succeeded in obtaining spectra of hydrogen in which some of the lines in this region are either absent or very greatly reduced in intensity, but I have not yet obtained a spectrum which represents a state of things precisely similar to that which obtains in this nebula.

FRIDAY, AUGUST 25.

The following Papers were read :—

1. *On the Absolute Measurement of Electric Currents.* *By* Professor Lord Rayleigh, *F.R.S.*

The accurate absolute measurement of currents seems to be more difficult than that of resistance. The methods hitherto employed require either accurate measurements of the earth's horizontal intensity, or accurate measurements of coils of small radius and of many turns. If in the latter measurement we could trust to the inextensibility of the wire, as some experimenters have thought themselves able to do, the mean radius could be accurately deduced from the total length of wire and the number of turns; but actual trial has convinced me that fine wire stretches very appreciably under the tension necessary for winding a coil satisfactorily. Kohlrausch's method, in which the same current is passed through an absolute galvanometer, and through a coil suspended bifilarly in the plane of the meridian, is free from the above difficulty; but it is not easy so to arrange the proportions that the suspended coil shall be sufficiently sensitive, and the galvanometer sufficiently insensitive. In this method, as in that of the dynamometer, the calculation of the forces requires a knowledge of the moment of inertia of the suspended parts.

When the electromagnetic action is a simple attraction or repulsion, it can be determined directly by balancing it against known weights. In Mascart's recent determination a long solenoid is suspended vertically in the balance, and is acted upon by a flat coaxial coil of much larger radius, whose plane includes the lower extremity of the solenoid. This arrangement, though simple to think about, does not appear to be the one best adapted to secure precise results. It is evident that a large part of the solenoid is really ineffective, those turns which lie nearly in the plane of the flat coil being but little attracted, as well as those which lie towards the further extremity. The result calculated from the total length of wire (even if this could be trusted), the length of the solenoid, and the number of turns, has an appearance of accuracy which is illusory, unless it can be assumed that the distribution of the wire over the length is strictly uniform. It would appear that all the turns of the suspended coil should operate as much as possible, that is, that

the suspended coil should be compact, and should be placed in the position of maximum effect.

There is a further incidental advantage in this arrangement, which it is the principal object of the present note to point out. The expression for the attraction involves as factors the product of the numbers of turns, the square of the current, and a function of the mean radii of the two coils, and of the distance between their mean planes. Now, as may be seen from the fact that the square of a current is already of the dimensions of a force, this function of three linear quantities is itself of no dimensions. In determining its actual value we should in general be subject to three errors; but when the position is such that the function (for two given coils) is a maximum, the result is practically dependent only upon the two mean radii, and being of no dimensions can involve them only in the form of a *ratio*. In order then to calculate the result, all that it is necessary to know with precision is the ratio of the mean radii of the two coils. This ratio can be obtained electrically, with full precision, and without any linear measurements. For, if the two coils considered as galvanometer coils are brought coaxially into the same plane, the ratio of their constants can be found by the known method of dividing a current between them in such a way that no effect is produced upon a small magnet suspended at their common centre. The ratio of the resistances in multiple arc gives the ratio of the currents, and this again (subject to small corrections for the finite size of the sections), gives the ratio of the mean radii.

It appears that in this way all that is necessary for the absolute determination of currents can be obtained without measurements of length, or of moments of inertia, or even of absolute angles of deflection. In practice it will be desirable to duplicate the fixed coil, placing the suspended coil midway between two similar fixed ones, through which the current passes in opposite directions. A rough approximation to the condition of things above described will be quite sufficient.

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2. *On the Duration of Free Electric Currents in an Infinite Conducting Cylinder.* *By* Professor Lord Rayleigh, *F.R.S.*

Taking the axis of the cylinder as that of z, we suppose that the currents are functions of $\sqrt{(x^2+y^2)}$, or r, only, and flow in the circles $r=$ constant.

From the equations given in Maxwell's 'Electricity,' vol. ii. §§ 591, 598, 607, 610, 611, we may deduce for a conductor of constant μ

$$\left(\frac{d^2}{dx^2}+\frac{d^2}{dy^2}+\frac{d}{dz^2}\right)c=4\pi\mu C\frac{dc}{dt}$$

with similar equations for b and a.

In the present case the magnetic forces b and a vanish, and c is a function of r only. Thus

$$\left(\frac{d^2}{dr^2}+\frac{1}{r}\frac{d}{dr}\right)c=4\pi\mu C\frac{dc}{dt},$$

or if c varies as e^{-nt},

$$\left(\frac{d^2}{dr^2}+\frac{1}{r}\frac{d}{dr}+4\pi\mu n C\right)c=0,$$

the solution of which, subject to the condition of finiteness at the centre, is

$$c=AJ_0(\sqrt{4\pi\mu n C}\,.\,r)=AJ_0(kr).$$

To determine the admissible values of n, we have only to form the condition which must be satisfied at the boundary of the cylinder $r=R$. It is evident that the magnetic force must here be zero, so that the condition is

$$J_0(\sqrt{4\pi\mu n C}\,.\,R)=0.$$

The roots of the function are,

2·404, 5·520, 8·654, 11·792, &c.

For the principal mode of longest duration

$$c=AJ_0(2{\cdot}404\,r/R)$$

and $$n = \frac{2 \cdot 404^2}{4\pi\mu CR^2}$$

If τ be the time in which the amplitude sinks in ratio e : 1

$$\tau = \frac{1}{n} = \frac{4\pi\mu CR^2}{(2 \cdot 404)^2}$$

For copper in $C.G.S.$ measure $C = \frac{1}{1642}$, $\mu = 1$,

and thus $$\tau = \frac{R^2}{800} \text{ nearly}$$

In order that τ should be one second, the diameter of the cylinder would have to be about two feet.

3. *On the Equilibrium of Liquid-conducting Surfaces charged with Electricity.*[1] *By* Professor LORD RAYLEIGH, *F.R.S.*

4. *On a New Hand Dynamo-Machine.* *By* W. H. PREECE, *F.R.S.*

The author described a compact dynamo-machine designed by the Baron de Meritens for lecturing, teaching, and laboratory purposes. It consists of a Pacinotti armature rotating in an electro-magnetic field of the Gramme type. It gives a continuous current and produces an electromotive force of 70 volts. The resistances of the armature and of the field magnets are 4 ohms each. One man can thus produce a current of one ampère through an Edison incandescent lamp with great ease, and four men can illumine four such lamps. The cost of the instrument was 350 francs in Paris.

5. *On Secondary Batteries, with special reference to Local Action.* *By* J. H. GLADSTONE, *Ph.D., F.R.S.*

The elements of which a Planté battery and its various modifications consist are metallic lead, peroxide of lead, and dilute sulphuric acid. The reaction that takes place is the combination of the positive metal with SO_4, forming $PbSO_4$, and the reduction of the PbO_2 by means of the hydrogen to PbO, which in the presence of sulphuric acid is also converted into sulphate of lead and water. The amount of force which can be obtained from a cell depends upon the amount of peroxide of lead which is capable of being reduced. Now the negative plate of these secondary batteries is itself an arrangement of lead and lead peroxide, and if immersed in dilute sulphuric acid galvanic action is at once set up. This 'local action' is, fortunately, soon diminished by the formation of the badly-conducting sulphate of lead upon the surfaces of the lead plate and crystals of peroxide. When the two plates are brought into connection the discharge takes place between them, but the local action on the negative plate is not stopped. This is shown by the much larger amount of sulphate of lead produced on the negative than on the positive plate. In three experiments in which the resistance was varied this increase amounted to 15, 34, and 53 per cent. respectively. The amount of available peroxide of lead that may have been thus destroyed on any negative plate is not easily recognised, for the electromotive force is not affected, and the current obtainable in the first instance is not much reduced, though of course the same amount of work cannot be got out of the battery.

This local action takes place also during the formation of a cell. One of the proofs of this is that much more oxygen is absorbed than could possibly be absorbed in the oxidation of the minium used in a Faure cell; indeed, in one experiment which was continued for 115 hours, it was found that a small amount of oxygen was being continuously absorbed, though the main action was complete in less than 40 hours. This was attributed to the formation of sulphate at the expense of the lead plate, and its subsequent oxidation.

As this local action impairs the value of these secondary batteries, it becomes

[1] *Phil. Mag.*, September, 1882.

an important problem to ascertain what modification of the present arrangements will minimise if not entirely prevent it.

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6. *Demands of a System of Electrical Distribution.* *By* F. J. SPRAGUE, *U.S. Navy.*

The multiple arc system of distribution, having the advantages of simplicity, independence of circuits, and reliability, is the only one which can have any wide-spread application for domestic purposes where the current is taken directly from the generators. Considering a single machine, the external resistance diminishes with the increase in the number of circuits, the current varies inversely with the external resistance, and the potential at the terminal remains constant, while the electromotive force of the machine does not. If r is the ratio of external to internal resistance, E the electromotive force developed when these resistances are equal, and E' the electromotive force when r has some other value than one, then

$$E' = \frac{E}{2}\left(\frac{1}{r} + 1\right)$$

The curve being traced shows:—

1st. In a single generator the electromotive force is not proportional to the number of lights or motors or the current developed.

2nd. No matter how high the external resistance, or how limited the number of derived circuits, the electromotive force of a machine required to maintain a fixed difference of potential at the terminals, can never be less than one-half that developed when the external and internal resistances are equal.

3rd. The increase of electromotive force required as the external resistance decreases, or the number of derived circuits is increased, is very gradual up to the point where the external resistance is three or four times the internal, beginning then to rise more rapidly.

4th. When the external resistance falls below the internal, the rise is very rapid, and if this difference is marked, then it becomes impossible to maintain a fixed difference of potential, because of the great increase necessary in the strength of the magnetic field and the velocity of the armature. A great amount of heat, and consequently wasted energy, would be developed in the armature.

In a general system there would be a low external resistance and large currents, the energies of which are proportional to the squares.

Consequently the resistance of lamps should be high; but there is a limit, determined principally by the illumination required, and the potential. Since for a given illuminating surface small section carbons give the highest resistance and least mass, we should diminish the diameter and increase the length and resistance of carbon, meeting this by an increase of potential. Several reasons, one of the principal being safety, indicate about 150 volts as the limit at the terminal of the lamp circuits. With a given standard, it is necessary to have also lamps of higher power. For this we must increase the width of carbons, or their length, while the specific resistance is reduced. Flat carbons are preferable to circular ones, because the resistance of the last diminishes as the square of the increase of surface.

The energy required for a system is expended in overcoming friction and inertia, magnetising useless parts, and generating currents which do work in the armature, field coils, conductors, and lamps. Of these, the work required for friction and inertia, and for the field magnets, is about the same whatever the number of lights on a single machine. Various considerations lead me to the following conclusions:—

1. The resistance of the armature of the generator should be as low as possible compatible with the power to furnish the necessary electromotive force.

2. The generator should be able to produce this electromotive force with the field magnet at less than the maximum economic saturation, and at a velocity less than that at which the armature can be safely run, in order that there may be a margin for increased efficiency in case of an unexpected demand.

3. The lamps and motor should have a high resistance, the standard lamp not higher than 475 to 500 ohms.

4. The resistance of the conductor should be as low as practicable, and should be graded in size for the current required.

5. The electromotive force of the generator should never rise to over 170 volts.

6. The lamps should be simple of construction, durable and cheap, and all alike.

7. The generator and the engine should be of the most substantial construction.

8. The points of derivation should all have, and all be maintained at, the same difference of potential as nearly as possible.

9. The energy necessarily lost in armature and conductors of any fixed resistance for lamps of the same absolute economy varies inversely as the resistance of the lamps, or as the squares of the currents used.

10. Since in a single generator the total power used is not proportional to the number of lamps in circuit, a machine should be run nearly to its maximum capacity.

11. There should not be a single generator or a single circuit which may be destroyed; but there should be such an arrangement that the external demands, both with regard to resistance and current required, may be met by suitable changes in the resistance and supply of the generative system.

12. The relation of internal and external resistance should be in a system the same as exists in a single generator when worked to nearly its full capacity.

13. With such proper relation of internal and external resistance the electromotive force will vary but slightly, and the power used will be very nearly proportional to the number of lamps or the current developed.

14. Insulation of conductors and of the armatures should be good, and provision made to prevent fire arising from an abnormal increase of current.

15. Means should exist of accurately measuring the current used.

16. A large system should be as economical as a single generator worked nearly to its full capacity, and should be capable of regulation with the same ease.

Much has been said about the subdivision of the electric light and the subdivision of the current; and such subdivision of electricity has been the great bugbear in the distribution of power and light by its means. This term, while conveying an idea, is in reality essentially wrong. It implies the existence of a current, the expenditure of energy, before the required subdivision of such current is made. A current is a function, not only of potential, but of potential and resistance. We desire to establish a certain potential, or difference of potential, and to maintain this so that when a circuit is established, a channel opened, a current may be established in that circuit. We do not divide a current, do not divide a potential, but having established a difference of potential in two conductors, we open one or more paths, and a current flows over these paths dependent on their resistance, and independent of each other, and such additional current having been formed, the current over the main conductor is increased by just such increment, which increment did not exist until the new path was made. There has been no subdivision of a current, there has been a creation. Such new current having been made, of course more power must be supplied to maintain the existing potential.

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7. *On the Comparison of the Mercury with the Hydrogen Thermometer.* *By* Professor J. M. Crafts.

A thermometer filled with air or some other gas is the standard instrument for measuring temperature, and a correction is necessary to bring the results of a mercury thermometer into accord with this standard. The only table of corrections for temperatures above 100 degrees Centigrade is that published by Regnault thirty years ago. It has been found that this does not apply to the instruments in use to-day, and a new series of determinations has been made of a number of French and of one German thermometer, giving results so concordant that a new table for general use can be founded upon them.

The deviation of the mercury from the gas thermometer is much smaller than

that found by Regnault, and lead-glass and common German glass have given nearly identical results.

A method of treatment to prevent considerable changes of the zero points of mercury thermometers is proposed to be applied to all thermometers before graduation, and a new method for graduating thermometers in short sections is recommended, which is founded upon a series of determinations of the boiling points of certain pure substances.

SATURDAY, AUGUST 26.

The following Report and Papers were read:—

1. *Report on Recent Progress in Hydrodynamics. Part* II.—*Special Problems. By* W. M. HICKS, *M.A.*—See Reports, p. 39.

2. *On the Rotation of a Homogeneous Liquid Ellipsoid.*[1] *By* A. G. GREENHILL, *M.A.*

3. *On a Proof of Wilson's Theorem.*[2] *By* Professor CAYLEY, *F.R.S.*

4. *Integration of an Equation connected with the Elliptic Functions. By* Captain P. A. MACMAHON, *R.A.*

In 'Comptes Rendus,' tom. lxvi. p. 1144, Allegret has considered the integral of

$$\frac{dx}{X^{\frac{2}{3}}}+\frac{dy}{Y^{\frac{2}{3}}}=0,$$

where

$$X=A+Bx+Cx^2+Dx^3$$
$$Y=A+By+Cy^2+Dy^3,$$

the result being

$$A+\left(\frac{yX^{\frac{1}{3}}-xY^{\frac{1}{3}}}{x-y}\right)^3+axy\left\{D-\left(\frac{X^{\frac{1}{3}}-Y^{\frac{1}{3}}}{xy}\right)^3\right\}=0$$

where a is the arbitrary constant.

He does not further rationalise it. To obtain the result in a rational form, consider the equation

$$\frac{dx}{\{(x-a)(x^2-2px+q)\}^{\frac{2}{3}}}+\frac{dy}{\{(y-a)(y^2-2py+q)\}^{\frac{2}{3}}}=0$$

and reducing to elliptic integrals by the substitutions

$$\frac{X}{(x-a)^3}=x_1^{\,3},\qquad \frac{Y}{(y-a)^3}=y_1^{\,3}$$

we have

$$\frac{dx_1}{\sqrt{(x_1^{\,3}-b^3)}}+\frac{dy_1}{\sqrt{(y_1^{\,3}-b^3)}}=0,$$

where

$$b^3=\frac{q-p^2}{a^2-2pa+q};$$

Euler's integral of which is

$$\left\{\frac{X_1\pm Y_1}{x_1-y_1}\right\}^2=x_1+y_1+z_1,$$

where $X_1=\sqrt{(x_1^{\,3}-b^3)}$, $Y_1=\sqrt{(y_1^{\,3}-b^3)}$, and z_1 is the arbitrary constant.

Now, z_1 is such that

$$\int_{x_1}^{\infty}\frac{dx_1}{X}+\int_{y_1}^{\infty}\frac{dy_1}{Y_1}=\int_{z_1}^{\infty}\frac{dz_1}{Z_1}=0,$$

[1] This has since appeared in the *Proceedings of the Cambridge Philosophical Society*, vol. iv.

[2] This has since appeared in the *Cambridge Messenger of Mathematics*, vol. xi.

where $$z_1 = \sqrt{(z_1^3 - b^3)};$$
and since if
$$x_1 = b + b\sqrt{3}\,\frac{1+cn\,u}{1-cn\,u}$$
$$y_1 = b + b\sqrt{3}\,\frac{1+cn\,v}{1-cn\,v}$$
$$z_1 = b + b\sqrt{3}\,\frac{1+cn\,w}{1-cn\,w}$$
then $$u + v + w = 0;$$
and when
$$\begin{array}{ll} x_1 = y_1 & \text{then } z_1 \text{ is finite,} \\ y_1 = z_1 & \quad ,, \quad x_1 \text{ is finite,} \\ z_1 = x_1 & \quad ,, \quad y_1 \text{ is finite;} \end{array}$$
we see that Euler's integral may be written in the forms
$$(x_1 + y_1 + z_1)(x_1 - y_1)^2 = (X_1 - Y_1)^2$$
$$(x_1 + y_1 + z_1)(y_1 - z_1)^2 = (Y_1 - Z_1)^2$$
$$(x_1 + y_1 + z_1)(z_1 - x_1)^2 = (Z_1 - X_1)^2,$$
or adding and reducing
$$3x_1y_1z_1 = 3b^3 + Y_1Z_1 + Z_1X_1 + X_1Y_1.$$

This equation (since X_1 Y_1 are rational in x and y) is, when cubed, the complete integral of the differential equation
$$X^{-\frac{2}{3}}dx + Y^{-\frac{2}{3}}dy = 0.$$
It will be found to be
$$27\,XYZ = \{3Dxyz + C(yz + zx + xy) + B(x + y + z) + 3A\}^3.$$
The developed equation is of the form
$$\begin{aligned} &\mathrm{a} + \mathrm{h}y + \mathrm{g}y^2 + \mathrm{p}y^3 \\ +\ &x\{\mathrm{h} + \mathrm{b}y + \mathrm{f}y^2 + \mathrm{q}y^3\} \\ +\ &x^2\{\mathrm{g} + \mathrm{f}y^2 + \mathrm{c}y^2 + \mathrm{r}y^3\} \\ +\ &x^3\{\mathrm{p} + \mathrm{q}y^2 + \mathrm{r}y^2 + \mathrm{d}y^3\} = 0. \end{aligned}$$
The coefficients, of which ten are different, are therefore derivable from a matrix of the form of the determinant which expresses the discriminant of the general quadric surface
$$u = \mathrm{a}x^2 + \mathrm{b}y^2 + \mathrm{c}z^2 + 2\mathrm{f}yz + 2\mathrm{g}zx + 2\mathrm{h}xy + 2\mathrm{p}x + 2\mathrm{q}y + 2\mathrm{r}z + \mathrm{d} = 0.$$
(Compare Cayley, ch. xiv. p. 340, 'Elliptic Functions.')

The result shows that the complete integral of the differential equation is an equation $u = 0$, where u is a symmetric cubi-cubic function of (x, y): that is, a symmetric function, cubic in regard to each variable separately.

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5. *On the Establishment of the Elementary Principles of Quaternions on an Analytical Basis.*[1] *By* GUSTAVE PLARR, *D.Sc.*

The writer is of opinion, that for the purpose of initiating the student into the knowledge of the principles of quaternions, it would be more convenient (to many minds at least) to have these principles established by the analytical method. This method presents the advantage of founding the analytical properties of vectors and quaternions on a clear basis, which is no other than definition, and assumption by definition, and of establishing the geometrical properties on these definitions by way of interpretation and deduction. This is also the method applied to the treatment of the more important applications of quaternions—we mean to say, the method which consists in analytical deduction followed by geometrical interpretation of the results.

The working principle by which the geometrical properties may be deduced will be the following: Assuming that the product of two vectors is to be effected

[1] A Paper by the same author, and bearing the above title, has been communicated by Professor Tait to the Royal Society of Edinburgh, and inserted in vol. xxvii., part II. (pp. 175 to 202), of the *Transactions* of that Society.

by the rule of *distributive multiplication*, then this *product must represent one and the same result, whatever the directions of the components of the factors may be.*

As to details of the way of proceeding, we refer the reader to our paper with the above title, printed in the 'Transactions of the Royal Society of Edinburgh,' vol. xxvii.; but in order to give an outline of its contents we may state that we consider in that paper two sets of expressions for two vectors, ρ and ϖ. Namely

$$(1^\circ)\quad \begin{cases} \rho = T\rho\, U\rho, \\ \varpi = T\varpi[U\rho \cos \rho\varpi + U\sigma \sin \rho\varpi], \end{cases}$$

σ being coplanar with ρ ϖ, and at right angles to ρ, on the same side as ϖ; and

$$(2^\circ)\quad \begin{cases} \rho = ia + jb + kc, \\ \varpi = ix + jy + kz, \end{cases}$$

i, j, k being a system of tri-rectangular unit-vectors of any orientation whatsoever.

Forming with each set the expressions

$$P = \rho\varpi - \varpi\rho, \quad Q = \rho\varpi + \varpi\rho,$$

and identifying P_1 with P_2, and Q_1 with Q_2, we are led to the conclusions:

(I°) That the expressions $U\rho\, U\sigma - U\sigma\, U\rho$, and similar ones in i, j, k, are vectors, perpendicular to $U\rho$, $U\sigma$, for the first expression, and perpendicular to j, k, in the case $jk - kj$, and so on.

(II°) That the expressions $U\rho\, U\sigma + U\sigma\, U\rho$, and similar ones in i, j, k, are *scalars*, and scalars of one and the same value, namely, the value being equal to zero. Further deductions present themselves easily.

The establishment of $(U\rho)^2 = -1$, $i^2 = -1$, &c., on the contrary, must be made dependent on the discussion of the product of vector factors at least *three* in number.

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6. *On Linear Syzygetic Relations between the Coefficients of Ternary Quadrics. By* Professor R. W. Genese, *M.A.*

Let $(a, b, c, f, g, h)(x, y, z)^2 = 0$ be a ternary quadric.

This represents various curves and surfaces according to the system of co-ordinates and the *locus in quo.*

To fix the ideas, consider x, y, z, as the trilinear co-ordinates of a point, so that the quadric represents a conic.

Now let

$$la + mb + nc + pf + qg + rh = 0$$

be a relation between the coefficients.

Then it is known that the conic is such that triangles can be inscribed in it which are self-conjugate with regard to a fixed conic; but also that if the multipliers be themselves connected by the relation

$$\begin{vmatrix} l, & r, & q \\ r, & m, & p \\ q, & p, & n \end{vmatrix} = 0$$

then the conic is such that two fixed points can be found which are conjugate with respect to it. In this case the conic $(l, m, n, p, q, r)(x, y, z)^2 = 0$ represents two straight lines, whose poles, with regard to the imaginary conic, $x^2 + y^2 + z^2 = 0$, are the two conjugate points.

If, however, *two* linear syzygetic relations be given, then these determine two pairs of conjugate points (and a connected pair). For, from the two relations, we can form the relation $(\lambda_{,}l + \lambda' l')a + \&c. = 0$, and choose $\lambda : \lambda'$, so that the symmetrical determinant is zero in three ways: these are not independent, for the polars of the conjugate points obtained are determined by

$$\lambda(l, m \ldots)(x, y, z)^2 + \lambda'(l_1' \, m^1 \ldots)(x, y, z)^2 = 0,$$

i.e., they are the joins in pairs of the points determined by $(l, m \ldots)(x, y, z)^2 = 0$, and $(l'n' \ldots)(x, y, z)^2 = 0$, and two pairs of joins clearly determine the third pair. This is Professor Hesse's theorem, viz., conics which divide harmonically two diagonals of a quadrilateral divide in the same way the third.

Three linear relations, it is known, determine an infinite number of such pairs, which lie in general on one cubic curve. The equation to this cubic is

$$\begin{vmatrix} x & o & o & l_1 & l_2 & l_3 \\ o & y & o & m_1 & m_2 & m_3 \\ o & o & z & n_1 & n_2 & n_3 \\ o & z & y & p_1 & p_2 & p_3 \\ z & o & x & q_1 & q_2 & q_3 \\ y & x & o & r_1 & r_2 & r_3 \end{vmatrix} = 0$$

If, however, two of the relations be such that the conic passes through two fixed points $(x_1, y_1, z_1)(x_2, y_2, z_2)$ the cubic contains as a factor the line joining these points.

Hence we obtain the identity

$$\begin{vmatrix} x & o & o & x_1^2 & x_2^2 & l \\ o & y & o & y_1^2 & y_2^2 & m \\ o & o & z & z_1^2 & z_2^2 & n \\ o & z & y & 2y_1z_1 & 2y_2z_2 & 2p \\ z & o & x & 2z_1x_1 & 2z_2x_2 & 2q \\ y & x & o & 2x_1y_1 & 2x_2y_2 & 2r \end{vmatrix} \equiv -2\{x,y_1,z_2\}\{lx_1x_2 + \&c + p(y_1z_2 + z_1y_2) + \&c.\}$$

where X_1, X_2, &c., are the minors of x_1, x_2, &c., in the first factor.

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7. *On the Rectifiable Spherical Epicycloid, or Involute of a Small Circle.* *By* Henry M. Jeffery, *F.R.S.*

1. As in plane geometry the involute of a circle is a terminal form of an epicycloid, so in spherics if a great circle roll on a small fixed circle, a point in its circumference will be the involute of the latter. This involute is rectifiable, as has been shown by Clairant and J. Bernouilli, and is its own polar curve.

2. In cycloidal and trochoidal curves the radius of curvature and the evolutes are conveniently expressed in terms of the perpendicular and radius vector.

Let p, r be the co-ordinates of the curve p', r' those of its evolute, ρ, ρ' their radii of curvature.

If $p = f(r)$ denote the curve, then as in planimetry, $\sin^2 p' = \sin^2 r - \sin^2 p$, and since $\frac{\sin p}{\sin r} = \sin r \frac{d\theta}{ds}$, $\cos r' = \cos r \cos \rho + \sin p \sin \rho$.

In differentiating, ρ, r' remain constant, while r, p vary.

$$\tan \rho = \frac{\sin r}{\cos p} \frac{dr}{dp}.$$

(Mathematical Tripos Examination, Jan 17, 1882.)

By eliminating from these four equations, the equation to the evolute, or conversely to the involute, may be obtained.

3. In the small circle $p' = r' = a$: hence the involute of the circle is defined by the equation

$$\sin^2 r - \sin^2 p = \sin^2 a.$$

Since the equation is unaltered, when $\frac{\pi}{2} - p$, and $\frac{\pi}{2} - r$, are substituted for r and p, this epicyloid is its own polar curve.

4. To find the involute of the involute of a small circle.

By § 2 the relations of the co-ordinates are

$$\cos r' = \cos r \cos R + \sin p \sin R, \text{ where } \tan R = \frac{\sin r}{\cos p} \frac{dr}{dp}, \ \sin^2 p' = \sin^2 r - \sin^2 p.$$

In this epicycloid by § 3, $\cos^2 r' + \sin^2 p' = \cos^2 a$.

The differential equation to its involute is

$$\sin^2 a = \cos^2 r + \sin^2 p - (\cos r \cos R + \sin p \sin R)^2.$$

To separate the variables, let $\rho \cos \theta = \cos r$, $\rho \sin \theta = \sin p$.

$$\rho^4 (d\theta)^2 = (\rho^2 - \sin^2 a)\{(d\rho)^2 + \rho^2 (d\theta)^2\}$$

whence $\rho \dfrac{d\theta}{d\rho} \sin a = \surd(\rho^2 - \sin^2 a)$.

The integral of this equation defines the involute

$$\theta = \operatorname{cosec} a \surd(\rho^2 - \sin^2 a) - \cos^{-1}\left(\frac{1}{\rho} \sin a\right).$$

After replacing the values of ρ, θ, this becomes

$$\tan^{-1}\left(\frac{\sin p}{\cos r}\right) = \operatorname{cosec} a \surd(\cos^2 r + \sin^2 p - \cos^2 a) - \cos^{-1}\surd\frac{\sin a}{(\cos^2 r + \sin^2 p)}.$$

5. If $\sin a = \frac{1}{2}$, or the circumference of the rolling circle is double that of the fixed circle, the epicycloid is the spherical cubic with a triple focus and triple cyclic arc.

$$\tan^2 y\,(\tan x - \surd 3) + (\tan x - \tfrac{1}{3}\surd 3)^3 = 0.$$

6. The involute of a small circle is rectifiable.

$$\text{Since } \frac{\sin p}{\sin r} = \sin r \frac{d\theta}{ds}, \text{ and } \sin^2 r - \sin^2 p = \sin^2 a.$$

$$ds \sin a = \sin r\, dr,$$

$$s \sin a = \cos a - \cos r.$$

The arc varies as the distance of the moving point from the plane of the small circle.

7. On the quadrature of areas enclosed by the involute of a small circle.

Two spaces are selected, both bounded by the fixed circle and its involute; but the third limit may be (1) the rolling great circle, or (2) the radius-vector of the moving point.

In (1) an elemental area has been chosen by Clairant, which is comprised between the involute and two consecutive positions of the generating great circle.

If θ be the arc subtended at the fixed centre by the arc which has been traversed, and ϕ the equal length of the generating great circle, then

$$\theta \sin a = \phi, \ \cos r = \cos a \cos \phi.$$

$$\text{The area in (1)} = \int d\theta\,(\cos a - \cos r) = \cot a \int d\phi\,(1 - \cos\phi) = \cot a\,(\phi - \sin\phi).$$

Clairant remarks that if from this area a spherical sector be subtracted with ϕ for its vertical angle, the remainder would be strictly quadrable.

$$\text{In (2) the area} = \operatorname{cosec} a \int dr\,(\cos a - \cos r) \operatorname{cosec}^2 r \sin^2 p$$

$$= \cot a\,(\phi - \sin\phi) - \cos a \tan^{-1}(\tan\phi \operatorname{cosec} a) + \tan^{-1}(\sin\phi \cot a),$$

since $\cos r = \cos a \cos\phi$, $\sin p = \cos a \sin\phi$.

From this area also, if a certain spherical sector be subtracted, the remainder is strictly quadrable.

8. Bernouilli remarks that the apparent path of the sun's centre is an epitrochoid, affiliated to the rectifiable epicycloid or involute of a small circle.

'If the sun were to move in the ecliptic with a velocity equal to that which the tropic of Capricorn has to execute the diurnal motion, and so the time of a revolution of the sun in the ecliptic were to the time of revolution of the sphere, which constitutes the length of the natural day, in the same ratio which the radius of the ecliptic (or of the sphere) bears to the radius of the tropic as 1 : cos 23°30′, the centre of the sun would exactly describe a rectifiable epicycloid. But as the sun has its proper motion in the ecliptic much slower, the line which the centre of the sun describes between the two tropics during the space of a year by the combined common and proper motion will be a *cycloide allongée*, rather than a spiral, under the form that Tycho conceived.'

9. The preceding paragraphs are extracted in a condensed form from a memoir on spherical, cycloidal, and trochoidal curves, which will appear in the forthcoming number for October 1882 of the 'Quarterly Journal of Mathematics.'

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8. *On a Partial Differential Equation. By* J. W. L. Glaisher, *M.A., F.R.S.*

In the British Association Report for 1878, p. 469,[1] it is shown that $u = e^{a\surd(x^2 + yh)}$ is a particular integral of the partial differential equation

[1] See also *Phil. Trans.* 1881, p. 774.

$$\frac{d^2u}{dx^2}-a^2u=\frac{h^2}{x^2}\frac{d^2u}{dh^2} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

and it is deduced from this result that the ordinary differential equation

$$\frac{d^2u}{dx^2}-a^2u=\frac{p(p+1)}{x^2}u \quad . \quad . \quad . \quad . \quad . \quad (2)$$

has for its complete integral, when p is a positive integer, $u=AP+BQ$, where A and B are constants, and P and Q denote the coefficients of h^{i+1} in the respective expansions of $e^{a\sqrt{(x^2+xh)}}$ and $e^{-a\sqrt{(x^2+xh)}}$ in ascending powers of h.

The present note relates to the partial differential equation (1), which is satisfied by the three following values of u;

$$u=\int_0^\infty \cos at\,\phi\left(\frac{hx}{x^2+t^2}\right)dt \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (\text{i.})$$

$$u=\int_0^\infty \frac{x\cos at}{x^2+t^2}\phi\left\{h\left(x+\frac{t^2}{x}\right)\right\}dt \quad . \quad . \quad . \quad . \quad . \quad (\text{ii.})$$

$$u=\int_0^\infty e^{-\frac{1}{2}a\left(t^2+\frac{x^2}{t^2}\right)}\phi\left(\frac{hx}{t^2}\right)dt \quad . \quad . \quad . \quad . \quad . \quad . \quad (\text{iii.})$$

where ϕ denotes an arbitrary function.

To verify that (i.) satisfies the differential equation (1), we find by differentiation that

$$\frac{d^2u}{dx^2}-\frac{h^2}{x^2}\frac{d^2u}{dh^2}=\int_0^\infty \cos at\left[\frac{2hx(x^2-3t^2)}{(x^2+t^2)^3}\phi'\left(\frac{hx}{x^2+t^2}\right)-\frac{4h^2x^2t^2}{(x^2+t^2)^4}\phi''\left(\frac{hx}{x^2+t^2}\right)\right]dt$$

and, by a double integration of parts,

$$a^2u=\left[a\sin at\,\phi\left(\frac{hx}{x^2+t^2}\right)-\cos at\frac{2hxt}{(x^2+t^2)^2}\phi'\left(\frac{hx}{x^2+t^2}\right)\right]_{t=0}^{t=\infty}$$

$$+\int_0^\infty \cos at\left[\frac{2hx(x^2-3t^2)}{(x^2+t^2)^3}\phi'\left(\frac{hx}{x^2+t^2}\right)-\frac{4h^2x^2t^2}{(x^2+t^2)^4}\phi''\left(\frac{hx}{x^2+t^2}\right)\right]dt;$$

and the differential equation is therefore satisfied, subject only to the conditions that the integral (i.) is finite, and that the expression

$$a\sin at\,\phi\left(\frac{hx}{x^2+t^2}\right)-\cos at\frac{2hxt}{(x^2+t^2)^2}\phi'\left(\frac{hx}{x^2+t^2}\right)$$

vanishes when taken between the limits 0 and ∞.

Similarly it can be shown that (ii.) satisfies the differential equation if the integral is finite and if

$$\left\{\frac{ax\sin at}{x^2+t^2}-\frac{2xt\cos at}{(x^2+t^2)^2}\right\}\phi\left\{h\left(x+\frac{t^2}{x}\right)\right\}+\frac{2ht\cos at}{x^2+t^2}\phi'\left\{h\left(x+\frac{t^2}{x}\right)\right\}$$

vanishes when taken between the limits 0 and ∞ of t.

With regard to the integral (iii.), putting

$$w=t^2+\frac{x^2}{t^2},$$

we find

$$\frac{d^2u}{dx^2}=\int_0^\infty e^{-\frac{1}{2}aw}\left[\left(\frac{a^2x^2}{t^4}-\frac{a}{t^2}\right)\phi\left(\frac{hx}{t^2}\right)-\frac{2ahx}{t^4}\phi'\left(\frac{hx}{t^2}\right)+\frac{h^2}{t^4}\phi''\left(\frac{hx}{t^2}\right)\right]dt,$$

and

$$\frac{d^2u}{dh^2}=\int_0^\infty e^{-\frac{1}{2}aw}\frac{x^2}{t^4}\phi''\left(\frac{hx}{t^2}\right)dt;$$

whence

$$\frac{d^2u}{dx^2}-\frac{h^2}{x^2}\frac{d^2u}{dh^2}=\int_0^\infty e^{-\frac{1}{2}aw}\left[\left(\frac{a^2x^2}{t^4}-\frac{a}{t^2}\right)\phi\left(\frac{hx}{t^2}\right)-\frac{2ahx}{t^4}\phi'\left(\frac{hx}{t^2}\right)\right]dt.$$

Integrating by parts, we have

$$\int^\infty e^{-\frac{1}{2}aw}\phi\left(\frac{hx}{t^4}\right)dt=\left[e^{-\frac{1}{2}at^2}\times-\frac{1}{at}e^{-\frac{1}{2}a\frac{x^2}{t^2}}\phi\left(\frac{hx}{t^2}\right)\right]_{t=0}^{t=\infty}$$

$$+\frac{1}{a^2}\int_0^\infty e^{-\frac{1}{2}aw}\left[\left(\frac{a^2x^2}{t^4}-\frac{a}{t^2}\right)\phi\left(\frac{hx}{t^2}\right)-\frac{2ahx}{t^4}\phi'\left(\frac{hx}{t^2}\right)\right]dt,$$

and therefore the condition in order that the differential equation may be satisfied is that

$$\frac{1}{t}e^{-\frac{1}{2}a\left(t^2+\frac{x^2}{t^2}\right)}\phi\left(\frac{hx}{t^2}\right)$$

must vanish when taken between the limits 0 and ∞ of t.

The integrals (i.), (ii.), (iii.) were derived from known forms of the solution of the differential equation (2) by the substitution of $h\frac{d}{dh}$ for $p+1$ and the use of the formula

$$a^{h\frac{d}{dh}}\phi(h)=\phi(ah)$$

9. *On a Theorem in Elliptic Functions.* *By* J. W. L. GLAISHER, *M.A., F.R.S.*

The main object of the paper is to give a proof of the theorem, that if

$$\frac{u^n}{n!}=\frac{\operatorname{sn}^n u}{n!}+R^{(n+2)}\frac{\operatorname{sn}^{n+2}u}{(n+2)!}+R_n^{(n+4)}\frac{\operatorname{sn}^{n+4}u}{(n+4)!}+\ \&c.$$

then the R-coefficients are such that

$$(2n-2)!k^{2n-1}\operatorname{sn}^{2n-1}u=R_1{}^{(2n-1)}k\operatorname{sn}u+R_3{}^{(2n-1)}\frac{d^2}{du^2}k\operatorname{sn}u\ldots+R_{2n-}^{(2n-1)}\frac{d^{2n-2}}{du^{2n-2}}k\operatorname{sn}u,$$

$$(2n-1)!k^{2n}\operatorname{sn}^{2n}u=-R_0^{(2n)}+R_2^{(2n)}k^2\operatorname{sn}^2u+R_4^{(2n)}\frac{d^2}{du^2}k^2\operatorname{sn}^2u\ldots\cdot$$

where $R_0^{(2n)}$ is independent of u.

This theorem is proved by Jacobi on pp. 125–127 of the 'Fı but the following investigation is somewhat different.

It is easy to show that if $y=e^{a\arg\operatorname{sn}x}$, then y satisfies the difl

$$\left\{1-(1+k^2)x^2+k^2x^4\right\}\frac{d^2y}{dx^2}-\left\{(1+k^2)x-2k^2x^3\right\}\frac{dy}{dx}-$$

Let

$$y=1+Q^{(1)}x+Q^{(2)}\frac{x^2}{2!}+Q^{\ }\frac{x^3}{3!}+Q^{(4)}\frac{x^4}{4!}+\&c.,$$

and substitute this expression for y in the differential equation; we thus obtain, by equating to zero the coefficient of x^n,

$$Q^{(n+2)}=\{n^2(1+k^2)+a^2\}Q^{(n)}-n(n-1)^2(n-2)k^2Q^{(n-2)};$$

whence, since $Q^{(1)}=a$ and $Q^{(2)}=a^2$, it follows that

$$Q^{(2n-1)}=R_1^{(2n-1)}a+R_3^{(2n-1)}a^3+R_5^{(2n-1)}a^5\ldots+R_{2n-1}^{(2n-1)}a^{2n-1}$$

$$Q^{(2n)}\quad=R_2^{(2n)}a^2\ \ +R_4^{(2n)}a^4\ \ +R_6^{(2n)}a^6\quad\ldots+R_{2n}^{(2n)}a^{2n},$$

the R-coefficients being certain functions of k^2.

Putting $\arg\operatorname{sn}x=v$, we have

$$e^{av}=1+Q^{(1)}\frac{\operatorname{sn}v}{1!}+Q^{(2)}\frac{\operatorname{sn}^2v}{2!}+Q^{(3)}\frac{\operatorname{sn}^3v}{3!}+\&c.\qquad.\quad.\qquad(1)$$

and therefore, expanding e^{av} and writing for $Q^{(1)}$, $Q^{(2)}\ldots$ their values,

$$1+av+\frac{a^2v^2}{2!}+\frac{a^3v^3}{3!}+\frac{a^5v^5}{5!}+\&c.$$

$$=1+a\left(\operatorname{sn}v+R_1^{(3)}\frac{\operatorname{sn}^3v}{3!}+R_1^{(5)}\frac{\operatorname{sn}^5v}{5!}+\&c.\right)$$

$$+a^2\left(\frac{\operatorname{sn}^2v}{2!}+R_2^{(4)}\frac{\operatorname{sn}^4v}{4!}+R_2^{(6)}\frac{\operatorname{sn}^6v}{6!}+\&c.\right)$$

$$+a^3\left(\frac{\operatorname{sn}^3 v}{3!}+R_3^{(5)}\frac{\operatorname{sn}^5 v}{5!}+R_3^{(7)}\frac{\operatorname{sn}^7 v}{7!}+\&c.\right)$$
$$+\&c.,$$

whence we have

$$v=\operatorname{sn}v+R_1^{(3)}\frac{\operatorname{sn}^3 v}{3!}+R_1^{(5)}\frac{\operatorname{sn}^5 v}{5!}+\&c.,$$

$$\frac{v^2}{2!}=\frac{\operatorname{sn}^2 v}{2!}+R_2^{(4)}\frac{\operatorname{sn}^4 v}{4!}+R_2^{(6)}\frac{\operatorname{sn}^6 v}{6!}+\&c.$$

&c. &c.

and generally

$$\frac{v^n}{n!}=\frac{\operatorname{sn}^n v}{n!}+R_n^{(n+2)}\frac{\operatorname{sn}^{n+2} v}{(n+2)!}+R_n^{(n+4)}\frac{\operatorname{sn}^{n+4} v}{(n+4)!}+\&c.$$

so that the R's are the coefficients occurring in the expansions of $v, v^2, v^3 \dots$ in ascending powers of $\operatorname{sn} v$.

Now from (1) we have

$$\tfrac{1}{2}(e^{av}-e^{-av})=Q^{(1)}\operatorname{sn}v+Q^{(3)}\frac{\operatorname{sn}^3 v}{3!}+Q^{(5)}\frac{\operatorname{sn}^5 v}{5!}+\&c.$$

$$\tfrac{1}{2}(e^{av}+e^{-av})=1+Q^{(2)}\frac{\operatorname{sn}^2 v}{2!}+Q^{(4)}\frac{\operatorname{sn}^4 v}{4!}+\&c.;$$

replace a by $\frac{d}{du}$, and let the function operated upon be $\operatorname{sn} u$ in the first equation, and $\operatorname{sn}^2 u$ in the second; then since

$$e^{v\frac{d}{du}}\phi(u)=\phi(u+v),$$

we obtain the formulæ

$$\tfrac{1}{2}\left\{\operatorname{sn}(u+v)-\operatorname{sn}(u-v)\right\}=Q'^{(1)}\operatorname{sn}u.\operatorname{sn}v+Q'^{(3)}\operatorname{sn}u.\frac{\operatorname{sn}^3 v}{3!}+Q'^{(5)}\operatorname{sn}u.\frac{\operatorname{sn}^5 v}{5!}+\&c.$$

$$\tfrac{1}{2}\left\{\operatorname{sn}^2(u+v)+\operatorname{sn}^2(u-v)\right\}=\operatorname{sn}^2u+Q'^{(2)}\operatorname{sn}^2u.\frac{\operatorname{sn}^2 v}{2!}+Q'^{(4)}\operatorname{sn}^2u.\frac{\operatorname{sn}^4 v}{4!}+\&c.,$$

where $Q'^{(2n-1)}$ and $Q'^{(2n)}$ denote respectively

$$R_1^{(2n-1)}\frac{d}{du}+R_3^{(2n-1)}\frac{d^3}{du^3}+R_5^{(2n-1)}\frac{d^5}{du^5}\dots+R_{2n-1}^{(2n-1)}\frac{d^{2n-1}}{du^{2n-1}}$$

and

$$R_2^{(2n)}\frac{d^2}{du^2}+R_4^{(2n)}\frac{d^4}{du^4}+R_6^{(2n)}\frac{d^6}{du^6}\dots+R_{2n}^{(2n)}\frac{d^{2n}}{du^{2n}}.$$

Therefore by integration

$$\tfrac{1}{2}\int_0^u k\left\{\operatorname{sn}(u+v)-\operatorname{sn}(u-v)\right\}du=Q''^{(1)}k\operatorname{sn}u\operatorname{sn}v+Q''^{(3)}k\operatorname{sn}u\frac{\operatorname{sn}^3 v}{3!}+\&c.$$

$$\tfrac{1}{2}\int_0^u\int_0^u k^2\left\{\operatorname{sn}^2(u+v)+\operatorname{sn}^2(u-v)-2\operatorname{sn}^2u\right\}du\,du$$

$$=\left\{Q''^{(2)}k^2\operatorname{sn}^2u-R_0^{(2)}\right\}\frac{\operatorname{sn}^2 v}{2!}+\left\{Q''^{(4)}k^2\operatorname{sn}^2u-R_0^{(4)}\right\}\frac{\operatorname{sn}^4 v}{4!}+\&c.$$

where $Q''^{(2n-1)}$ and $Q''^{(2n)}$ denote respectively the operators

$$R_1^{(2n-1)}+R_3^{(2n-1)}\frac{d^2}{du^2}+R_5^{(2n-1)}\frac{d^4}{du^4}\dots+R_{(2n-1)}^{(2n-1)}\frac{d^{2n-2}}{du^{2n-2}},$$

and

$$R_2^{(2n)}+R_4^{(2n)}\frac{d^2}{du^2}+R_6^{(2n)}\frac{d^4}{du^4}\dots+R_{2n}^{(2n)}\frac{d^{2n-2}}{du^{2n-2}},$$

and $R_0^{(2n)}$ denotes the value of

$$R_4^{(2n)}\frac{d^2}{du^2}k^2\operatorname{sn}^2u+R_6^{(2n)}\frac{d^4}{du^4}k^2\operatorname{sn}^2u\dots+R_{2n}^{(2n)}\frac{d^{2n-2}}{du^{2n-2}}k^2\operatorname{sn}^2u$$

when u is put equal to zero.

Now it can be shown that

$$\int_0^u k \left\{ \mathrm{sn}\,(u+v) - \mathrm{sn}\,(u-v) \right\} du = \log \left(\frac{1 + k\,\mathrm{sn}\,u\,\mathrm{sn}\,v}{1 - k\,\mathrm{sn}\,u\,\mathrm{sn}\,v} \right)$$

$$= 2\left\{k\,\mathrm{sn}\,u\,\mathrm{sn}\,v + \tfrac{1}{3}k^3\,\mathrm{sn}\,^3u\,\mathrm{sn}\,^3v + \tfrac{1}{5}k^5\,\mathrm{sn}\,^5u\,\mathrm{sn}\,^5v + \&c.\right\},$$

$$\int_0^u\int_0^u k^2 \left\{ \mathrm{sn}^2\,(u+v) + \mathrm{sn}^2\,(u-v) - 2\,\mathrm{sn}\,^2u \right\} du\,du = -\log\,(1 - k^2\,\mathrm{sn}\,^2u\,\mathrm{sn}\,^2v)$$

$$= k^2\,\mathrm{sn}\,^2u\,\mathrm{sn}\,^2v + \tfrac{1}{2}k^4\,\mathrm{sn}\,^4u\,\mathrm{sn}\,^4v + \tfrac{1}{3}k^6\,\mathrm{sn}\,^6u\,\mathrm{sn}\,^6v + \&c.,$$

so that by equating the coefficients involving $\mathrm{sn}\,^{2n-1}v$ and $\mathrm{sn}\,^{2n}v$ we find that

$$\frac{k^{2n-1}\,\mathrm{sn}^{2n-1}u}{2n-1} = \frac{1}{(2n-1)!}\,Q''^{(2n-1)}\,k\,\mathrm{sn}\,u, \quad \frac{k\quad\mathrm{sn}\,^{2n}u}{2n} = \frac{1}{(2n)!}\left\{ Q''^{(2n)}\,k^2\,\mathrm{sn}\,^2u - R_0^{(2n)} \right\}$$

whence

$$(2n-2)!\;k^{2n-1}\,\mathrm{sn}\,^{2n-1}u = \left(R_1^{(2n-1)} + R_3^{(2n-1)}\frac{d^2}{du^2} + \ldots R_{2n-1}^{(2n-1)}\frac{d^{2n-2}}{du^{2n-2}} \right) k\,\mathrm{sn}\,u$$

$$(2n-1)!\;k^{2n}\,\mathrm{sn}^{2n}u = \left(R_2^{(2n)} + R_4^{(2n)}\frac{d^2}{du^2}\;\ldots\; + R_{2n}^{(2n)}\frac{d^{2n-2}}{du^{2n-2}} \right) k^2\,\mathrm{sn}\,^2u - R_0^{(2n)}$$

which are the equations written at the beginning of the paper.

MONDAY, AUGUST 28.

The following Reports and Papers were read:—

1. *Fifteenth Report of the Committee on Underground Temperature, containing a Synopsis of all previous Reports of this Committee.*—See Reports, p. 72.

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2. *On the Origin of Hail. By* Professor THEODORE SCHWEDOFF.

The size and weight of hail is frequently such as to cause all the usual theories as to the origin of hail in currents in the atmosphere to fail. The extreme lowness of their temperature forbids the idea that they are newly frozen. The researches of Abich, Secchi, Delcros, and others, leave no doubt that a hailstone is typically a figure of revolution, a sphere, oblate spheroid, discoid or toroid, often having hollowed poles and even annular. They are also frequently covered with large and well-developed crystals of clear ice. From these facts, Professor Schwedoff argues that they are of ultra-mundane or cosmical origin, and are in fact a species of meteorite. The strongest apparent confirmation of this hypothesis is to be found in the well-established fact of the existence of stony or pyritic nuclei in many hailstones, which nuclei have been proved to contain iron, nickel, &c.

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3. *Notes on Schwedoff's Theory of Hail. By* Professor SILVANUS P. THOMPSON.

(1) In confirmation of Schwedoff's views as to the typical form of hailstone being a figure of revolution, examples were cited from the observations of Darwin, Humboldt, Buist, Blanford, Blanchet, Colladon, Godefroy, and Loomis. The conical or pyramidal forms recently described as typical, by Professor Osborne Reynolds, could only be regarded as fragments broken from a spherical or spheroidal form of radial structure.

(2) As to Schwedoff's theory of a meteoric origin, this could, if accepted at all, only be accepted for certain cases of hail-falls. Becquerel had long ago divided hailstorms into 'ordinary' and 'extraordinary'; the latter being independent of local circumstances. If Schwedoff's theory were true, there should be regular hailstone days and hailstone periods. Some evidence appeared to be forthcoming

of a definite periodicity in the occurrence of hailstorms. It might, moreover, be reasonably doubted whether the attraction of such small bodies was sufficient to prevent their disappearance by evaporation, supposing them to be capable of existing outside the atmosphere of the earth.

4. *Second Report of the Committee on Meteoric Dust.*—See Reports, p. 90.

5 *Sun Light and Sky Light at High Altitudes. By* Captain W. DE W. ABNEY, *F.R.S.*

The author called attention to the fact that photographs taken at high altitudes show skies that are nearly black by comparison with bright objects projected against them; and he went on to show that the higher above the sea-level the observer went, the darker the sky really is, and the fainter the spectrum. In fact, the latter shows but little more than a band in the violet and ultra-violet at a height of 8,500 feet, whilst at sea-level it shows nearly the whole photographic spectrum. The only reason of these must be particles of some reflecting matter from which sunlight is reflected. The author traces this to watery stuff of which nine-tenths is left behind at the altitude at which he worked. He then showed that the brightness of the ultra-violet of direct sunlight increased enormously the higher the observer went, but only to a point, for the spectrum suddenly terminated at about 2,940 wave-lengths. This abrupt absorption was due to extra-atmospheric causes, and perhaps to space. The increase in brightness of the ultra-violet was such that the usually invisible rays L, M, and N could be distinctly seen, showing that the visibility of these rays depended on the intensity of the radiation. The red and ultra-red part of the spectrum was also considered. He showed that the absorption lines were present in undiminished force and numbers at this high altitude, thus placing their origin to extra-atmospheric causes. The B and A line he also stated could not be indubitably claimed as telluric lines, but might originate between the sun and our atmosphere, as they were as strong at the zenith as at the horizon at this altitude. The author confirmed the presence of derivative benzine and ethyl in the same region. He had found their presence indicated in the spectrum at sea-level, and found their absorption lines with undiminished intensity at 8,500 feet. Thus, without much doubt, hydrocarbon must exist between our atmosphere and the sun, and, it may be, in space.

6. *On the Distribution of Energy in the Solar Spectrum. By* Professor S. P. LANGLEY.

Of the whole solar energy nearly three-fourths, according to the author's measures, exists in the invisible portion below the red, yet of this great region very little is known, and of its extent upon the wave-length scale we are hitherto nearly ignorant. This ignorance arises from difficulties of research due to the compression of the infra-red end by the prism, and to the absence of means for separating and distinguishing individual rays in this crowded portion, or of determining their wave-length, since no law of connection between wave-lengths and indices of refraction can be said to be known.

The object of this communication is to present a map of the energy in this infra-red portion throughout its entire length, both on the prismatic and wave-length scale.

These charts (*exhibited*) show the distribution of the solar energy through this hitherto little known region, both on the wave-length and on the prismatic scale. The measures have been made by means of the linear balometer (*exhibited*), and the wave-lengths determined by one of the new concave gratings devised by Professor Rowland (*exhibited*). The energies are proportional to the ordinates, and the approximate wave-length of each ray is given.

It appears that the longest wave of solar energy which passes through our atmosphere has a length of about 0·0027mm., or in other words that the spectrum terminates near 27,000 of Ångström's scale.

This investigation is supplementary to another, which is designed to give the total absorption of each ray both in the solar and terrestrial atmospheres, for by repeating these measures at great altitudes, and by comparing the absorption at the centre and limb of the sun, for each ray, we can demonstrate the fact that the solar photosphere seen without any absorbing medium would appear deeply blue.

The method of determining the actual colour of the sun (photosphere) by a special use of Maxwell's colour-discs will be indicated, the approximate result being that this colour is that of the spectrum F. Some conclusions affecting our customarily received opinions as to the nature of white light will be indicated.

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7. *On a Similarity between Magnetical and Meteorological Weather.* *By* Professor BALFOUR STEWART, *M.A., LL.D., F.R.S.*

It has been hitherto supposed that there is no traceable likeness between the magnetical and meteorological changes of the globe. The former have been imagined to be of a cosmical nature affecting all parts of the earth at the same moment of time, while the latter are well known to be of a local and progressive nature. As a matter of fact all attempts to trace a likeness between simultaneous magnetical and meteorological phenomena have been without success.

There is, however, one class of magnetical phenomena that are of a progressive nature. I allude to the diurnal variations of the magnetic elements caused by the sun. Of these the solar-diurnal variation of the magnetic declination—that is to say, the variation of the position of a freely suspended magnetic needle, is that which has been most observed and is best understood.

It has been noticed that the diurnal progress of this variation is not unlike that of atmospheric temperature, the hourly turning-points in both being pretty nearly the same. Both phenomena too are regulated by the local time at the place of observation, and hence are of a progressive nature, travelling with the sun in his apparent course from east to west. Both phenomena too are subject to a well-marked annual fluctuation—the diurnal temperature range, for instance, or the difference between the indication of the maximum and the minimum thermometers being greater in summer than in winter, and in like manner the diurnal declination-range or the difference between the east and the west positions of a suspended magnet being greater in summer than in winter. Finally both phenomena appear to be subject to the influence of something which may be called *weather*. Sometimes we have very hot days and cold dry nights in which the diurnal temperature-range is very great, succeeded by close rainy weather in which the diurnal temperature-oscillation is very small. In like manner we have sometimes a very large and at other times a comparatively small diurnal oscillation of the magnetic needle, so that it too is affected by the influence of magnetic weather. The question which I now wish to put is the following: Is there any connection between these two weathers?—between temperature-range weather and between declination-range weather, both defined as above? Now there is, I think, preliminary evidence to show that both kinds of weather are due very greatly, if not altogether, to changes in the sun, a large declination-range and a large temperature-range denoting an increase of solar power. There is also evidence that temperature-range weather once produced travels from west to east, taking probably, on an average, eight or nine days to cross the Atlantic. There is also, I think, preliminary evidence that declination-range weather travels likewise from west to east, but quicker than temperature-range weather, taking about two days to cross the Atlantic. Now if this be true it might be expected that the declination-range weather of to-day should be found similar to the temperature-range weather six or seven days afterwards, so that by a study of the declination-range weather of to-day we should be able, with a certain measure of success, to predict the temperature-range weather six or seven days afterwards.

I have here given the train of thought which led to this investigation; but I ought to say that the results obtained do not depend upon the exact truth of every step of this train of reasoning. This is in reality a matter-of-fact investigation undertaken with the view of ascertaining whether or not there is any recognisable connection between these two weathers in Great Britain. The result obtained, I may add, was reported to the Solar Physics Committee, and by them communicated to the Royal Society. In order to avoid as much as possible the influence of locality I obtained, through the kindness of the Meteorological Council, the diurnal temperature-ranges at Stonyhurst, Kew, and Falmouth for the years 1871 and 1872. I obtained likewise, through the kindness of the Kew Committee, the diurnal ranges of magnetic declination at the Kew Observatory for the same two years, excluding disturbed observations. The temperature-ranges discussed are therefore the means of those at the three observatories above mentioned, and still further to tone down or equalise individual fluctuations the daily numbers exhibited are each the sum of four daily ranges, the two before and the two after. Finally, the object being to represent fluctuations of range rather than their absolute values, a daily series representing the mean of twenty-five daily numbers, has been obtained. Each daily number is thus compared with the mean of twenty-five daily numbers, both columns being symmetrically placed with regard to time, and the differences, whether positive or negative, between the two columns, is taken to represent temperature-range fluctuations.

A precisely similar course has been taken with respect to the Kew declination ranges.

By this means two years of daily numbers, sometimes positive and sometimes negative, representing temperature-range weather, and two years of daily numbers, sometimes positive and sometimes negative, representing declination-range weather, have been obtained.

The next object is to compare these two series with one another.

Now when two series of waves representing elevations and depressions come together, it is well known that we shall have the greatest result when the crests of the one series coincide with the crests of the other, and the smallest result—perhaps none at all—when the crests of the one series coincide with the hollows of the other. This, indeed, is the well-known explanation of musical beats.

Now if there be any marked likeness between the two weathers, and if it be true that declination-range weather precedes temperature-weather, the algebraic sum of the two sets of fluctuations representing these weathers will be greatest when the declination is pushed forward in point of time, so that the declination fluctuation of to-day shall be summed up with the temperature fluctuation six or seven days after. For suppose that the declination fluctuation of to-day is represented by a very large positive number; if the above theory be true, the temperature-fluctuation six or seven days afterwards will be represented by a large positive number also; so that we shall have the addition of two large positive numbers, whereas if we add the declination-weather of to-day to the temperature-weather of to-day it may chance that we are really adding a large positive to a large negative quantity, in which case the result will be very small.

It may also happen that this amount of precedence of declination-weather is greater at one season of the year than at another.

We have therefore to pursue a plan somewhat of the following nature. Take a month's temperature-weather, say, for the month of August, and add to it a month's declination-weather, extending, say, from July 21 to August 21; let the sum be 262. Here the declination-month has been pushed forward eleven days; next push it forward twelve days, and let the sum be 273; then thirteen days, and let the sum be 276; next, fourteen days, and let the sum be 270. It thus appears that the greatest sum is got by pushing the declination forward thirteen days, and we may therefore presume that at this season of the year thirteen days denotes the precedence of the declination weather. On this principle the following table has been constructed.

TABLE SHOWING BY HOW MANY DAYS THE DECLINATION-RANGE FLUCTUATION PRECEDES THE CORRESPONDING TEMPERATURE-RANGE FLUCTUATION.

Corresponding to middle of Month	Precedence of Declination		
	First Year	Second Year	Mean
January	—	8	8
February	6	4	5
March	6	5	5·5
April	5	5	5
May	9	9	9
June	9	9	9
July	12	11	11·5
August	13	13	13
September	9	10	9·5
October	7	5	6
November	10	7	8·5
December	12	—	12

It thus appears from each year that the precedence of declination is smallest about the equinoxes and greatest about the solstices, and it seems probable that were a considerable number of years so treated, more exact values would be obtained.

Having thus determined the amount of precedence of the declination from month to month, the next point is to ascertain to what extent the two fluctuations, when brought together, in a manner regulated by this precedence, show any distinct resemblance to each other. This has been done in a graphical representation which accompanies the report above-mentioned, and I think I may say that there is a considerable likeness between the two curves, the one exhibiting temperature-range weather, and the other declination-range weather, so pushed forward. It would thus seem as if a comparison of magnetical and meteorological weather might be made a promising subject of inquiry, besides being one which may perhaps lead to results of practical importance.

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8. *On a supposed Connection between the Heights of Rivers, and the Number of Sun-spots on the Sun. By* Professor BALFOUR STEWART, *M.A., LL.D., F.R.S.*

While a connection between the state of the sun's surface as regards spots, and the magnetic state of the earth may be considered as well-established, the fact of a connection between sun-spots and terrestrial meteorology is open to dispute. This question is still *sub judice*, and without attempting to assert the truth of such a connection, the following may perhaps be regarded as a slight contribution tending to throw light upon the subject. The heights of the rivers Elbe and Seine have already been examined by Fritz, who reported in favour of such a connection as would make a great height correspond to a large number of sun-spots, and all that I have done has been to treat the evidence in a somewhat different manner. I divide each sun-period, without regard to its exact length, into twelve portions (0) (1) (2) (3) &c., and put together the recorded river-heights corresponding in time to similar portions of consecutive sun-periods. I find by this means residual differences from the average representing the same law, whether we take the whole or either half of all the recorded observations, and whether we take the Elbe or the Seine. The results obtained are recorded in the following tables (0) denoting always the epoch of maximum sun-spots.

Table showing heights of Elbe.

(0·5) (1·5) (2·5) (3·5) (4·5) (5·5) (6·5) (7·5) (8·5) (9·5) (10·5) (11·5).

First 6.

+ 0·85 + 1·00 + 1·64 + 1·25 + 0·52 – 0·38 – 0·82 – 1·56 – 2·16 – 1·28 + 0·04 + 0·90.

Second 6.

+ 3·21 + 4·53 + 2·89 + 0·78 – 1·38 – 2·03 – 1·07 – 0·48 – 1·68 – 2·93 – 2·68 + 0·81.

Table showing heights of Seine.

First 5.

+ 1·84 + 1·57 + 1·25 – 0·02 – 0·54 + 0·09 – 0·26 – 0·82 – 2·07 – 1·56 – 0·21 + 0·73.

Second 5.

+ 1·07 + 1·75 + 0·79 – 0·03 – 1·04 – 1·70 – 1·51 – 1·16 – 1·24 – 0·13 + 0·45 + 2·15.

Without entering into minute particulars as to the details of the method by which these tables have been obtained, it may be stated that they exhibit an average oscillation in height something between a third and a quarter of a metre.

It would appear from these tables that there is a maximum of river-height about the time of maximum sun-spots, and another subsidiary maximum about the time of minimum sun-spots. It is of interest to know whether the same behaviour is followed by the river Nile. Through the kindness of General Stone Pacha, and through the Science and Art Department, South Kensington, information has been obtained about this river. This information is of two kinds—one part of it refers to the yearly heights of the Nile, reckoned above the zero of the Cairo Nilometer, the other to the date of maximum rise.

This information has been embodied in the following tables:—

Yearly heights of the Nile.

Year	Height	Year	Height
1849	2130	1864	2475
1850	2080	1865	2229
1851	2077	1866	2432
1852	2078	1867	2208
1853	2434	1868	2003
1854	2425	1869	2284
1855	2173	1870	2701
1856	2141	1871	2718
1857	2016	1872	2404
1858	1736	1873	2142
1859	1766	1874	2317
1860	2098	1875	2463
1861	2368	1876	2541
1862	2574	1877	1981
1863	2765	1878	2290

Table giving dates of maximum height of Nile, reckoned from beginning of September.

Mean of years	Date of maximum	Mean of years	Date of maximum
1849–1850	64	1864–1865	33
1850–1851	54	1865–1866	57
1851–1852	63	1866–1867	38
1852–1853	60	1867–1868	11
1853–1854	68	1868–1869	52
1854–1855	48	1869–1870	96
1855–1856	43	1870–1871	100
1856–1857	37	1871–1872	79
1857–1858	10	1872–1873	22
1858–1859	71	1873–1874	33
1859–1860	116	1874–1875	88
1860–1861	80	1875–1876	82
1861–1862	84	1876–1877	31
1862–1863	89	1877–1878	40
1863–1864	41		

It will be seen from the first of these two Nile tables, that we have maximum heights at 1863 and 1871, years shortly after the epoch of maximum sun-spots, also, subsidiary maxima at 1853, 1866, and 1876, years near the epoch of minimum sun-spots. So far, then, the Nile agrees with the European rivers in showing a maximum of height about the time of maximum sun-spots, and a subsidiary maximum about the time of minimum sun-spots, only this subsidiary maximum is greater than for the European rivers already named.

From the second Nile table it will be seen that the date of maximum heights appears to be latest on those years for which the yearly height is greatest, so that if we plot curves from the two tables, these curves will be found to be very like each other. Now the present year is perhaps not very far removed from a solar maximum, and I am thus induced to think that the Nile may this year be somewhat late in attaining its maximum rise.

TUESDAY, AUGUST 29.

The following Report and Papers were read:—

1. *Report of the Committee for constructing and issuing practical Standards for use in Electrical Measurements.*—See Reports, p. 70.

2. *Suggestions regarding the Extension of the Practical System of Units. By* Dr. C. W. Siemens, *F.R.S.*

3. *On a new Form of Galvanometer for Measuring Currents and Potentials in Absolute Units. By* Professor Sir William Thomson, *F.R.S.*

4. *On Electric Meters. By* C. Vernon Boys.

The electric meters to which attention is drawn are the energy meter and the vibrating current meter. The first gives the amount of energy expended by an electric current in any portion of a circuit during a time, the second gives the quantity of electricity that has passed in a conductor during a time. As the first is fully described in the 'Phil. Mag.' of February 1882, I do not propose to describe it at length. It consists essentially of two parts—an indicator, showing the rate at which electric energy is being expended at a time, and an integrator, to sum these indications.

The indicator depends on the principle that the force exerted between two conductors—one conveying the main, and the other, of high resistance, carrying a shunt current—is proportional to the energy expended by the current between the points to which the shunt is connected. The shunt circuit consists of a movable solenoid, wound with a great length of fine wire, the upper half in one direction, and the lower half in the opposite direction. This is suspended in the annular space between two fixed solenoids, through each of which the main current passes in the same direction, so that the upper half is drawn in and the lower pushed away from the fixed coils. It is suspended from one end of a beam, and balanced with a counter-weight, and the motion of the beam is resisted by a pendulum-weight. Under these conditions the tangent of the inclination of the beam is proportional to the energy of the current, which may therefore be read off on a straight scale of equal parts. This construction, as I have shown in the paper referred to, absolutely eliminates inequalities due to the movement of the coils.

The integrating mechanism, which automatically sums the readings given by the indicator, is a development of the 'cart' integrator described in the 'Phil. Mag.' of May 1881. This instrument is an exact mechanical equivalent of the mathematical principle of integration, which it illustrates most perfectly. Though

not convenient for practical purposes, it gave rise to the disc-cylinder integrator, which is all that can be desired. This consists of a cylinder which is moved longitudinally along its axis, while its surface is in contact with a disc. If the plane of the disc is parallel to the axis of the cylinder, the latter will not rotate when moved longitudinally; if inclined, the revolution of the cylinder will be proportional to the tangent of such inclination × the longitudinal movement. During the return stroke of the cylinder, its surface must rest against a disc on the opposite side, that the revolution may continue in the same direction. The double change of movement is effected by a 'mangle-motion,' driven by clockwork, and the inclination of the discs by the beam of the indicator. The number of revolutions of the cylinder will then be a measure of the total energy expended. The author felt bound to mention that Professor Abdank Abakanowicz had previously invented an integrator depending on the same mathematical principles, but, so far as he could learn, had not applied them to practical purposes. The author had been accused, not by Professor Abakanowicz, but by others, of pirating his invention; but, as he had never heard of it till he had completed his own, he was innocent of such a charge.

Besides the simple integrator already explained, he described a series of machines by which squares, products, quotients, and reciprocals may be directly integrated; among them is a polar planimeter, which is an exact mechanical translation of the polar expression, $\frac{1}{2}\int r^2 d\theta$; but, as he had not yet applied them to practical purposes, he did no more than allude to them. For the same reason he referred only to the apparatus for calculating efficiency; *i.e.* apparatus that will automatically divide the speeds with which two integrals are growing one into the other and continuously record the quotient.

Of the vibrating electric meter it is not possible to give an account in the space of this abstract.

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5. *On a new Electrical Contact Maker.* *By* Professor H. S. Hele Shaw.

The author first called attention to the want of an absolutely reliable, and at the same time sufficiently sensitive, electrical contact-maker. Such an instrument is often required to measure or control the relative motion of bodies in conjunction with delicate clockwork. He then proceeded to discuss the ways in which such contact may be made. In theory, there really is no distinction in the modes of doing this, but practically they may be separated into—

(1) Relative motion of the two terminal surfaces, normal to both.

(2) Motion tangential to both.

(3) Motion compounded of these two.

These modes were separately discussed, and also the various objections with all when solid terminals are used. The use of a liquid terminal, with which the other terminal, being solid, is brought into contact, obviates most of these objections. Of all liquids, mercury is the only one which can practically be employed. There are, however, two objections to its use which have prevented its being hitherto adopted for more than temporary and experimental purposes. These are:—

(1) The fact that it readily combines with oxygen on the passage of the electric spark.

(2) The difficulty of making a contact-maker of this kind portable.

The earliest form of instrument in which the author had endeavoured to overcome these difficulties, was then shown on a diagram and described. Its principle of action is briefly this. A short glass tube, closed at the upper end (such as an inverted test-tube), is filled with mercury, and inverted in a vessel of mercury. The mercury in the tube is then partially displaced by hydrogen gas. A very light bent lever, consisting of a platinum wire, passes through the mercury into the gaseous space, and there makes contact between the mercury below, and a smaller quantity of mercury in an insulated capsule above the other portion, but within the tube. This lever works on a pivot, being actuated from the outside by the escapement of an ordinary clock, and is extremely sensitive in its action. The positive and negative poles of the terminals are respectively connected with the mercury in the capsule and that in the vessel below. It is evident that, although the lever is

always in electrical contact with the latter, the circuit is only completed when it is brought into contact with the former. Accounts of experiments showing the satisfactory action with this apparatus were then given. Finally, the most recent form of apparatus which is portable was illustrated and described.

6. *On a Machine for ruling large Diffraction Gratings.* *By* A. MALLOCK.

Considerable interest attaches to the ruling of diffraction gratings, both on account of the mechanical difficulties involved in their production, as well as the admirable results which are obtained by their means when used for the purpose of analysing light.

The author did not intend to enter into the general theory of diffraction gratings, further than was necessary to point out the kind of accuracy which must be attained in ruling them if they are to give anything approaching the best results; but merely to give a short description of a machine made by him for the production of large gratings, and to mention some of the results obtained by it.

In all optical apparatus, whether lenses, prisms, mirrors, or diffraction gratings, the unit of length in which errors or deviation from the form or position of lines must be reckoned, is the wave-length of the light dealt with, and it has been shown by Lord Rayleigh, and is indeed tolerably obvious when once pointed out, that if, as is generally the case, the object of an optical surface is to cause the whole of a wave-front of finite area to reach a certain point in the same phase, a result not differing much from the best possible will be obtained, if the errors of the surface are such as not to cause an average disagreement of phase of more than one-fourth of a wave-length at the focal point.

The actual value of the permissible error indicated by the above condition is, for nearly perpendicular refraction and reflection, in glass about half a wave-length, and in mirrors about one-eighth of a wave-length. For further information on these points, the reader is referred to papers by Lord Rayleigh in the 'Philosophical Magazine' (October and December 1879, and January 1880). The surfaces on which diffraction gratings are ruled should have an accuracy of this kind, and the accuracy with which the lines of the grating are placed should be such that the projection of their errors of position on the path of the diffracted ray should not be greater than one-fourth of a wave-length for the first spectrum, or $\frac{1}{4n}$ for the nth spectrum, if the performance of the grating in that order of spectrum is to approach perfection.

These remarks apply when the angle between the incident and diffracted ray is not very large, *i.e.* when the distance between the lines is a considerable multiple of the wave-length. In the limiting case in which a diffraction spectrum can be formed, which is when the lines are only separated by one-half a wave-length, the permissible error in their position becomes, as in case of mirrors, one-eighth of a wave-length.

The definition of a grating depends, *cæteris paribus*, on its width, in the same way that that of a telescope depends on the diameter of the object-glass. It is very doubtful if any optical work hitherto produced approaches the extreme exactness which one-eighth wave-length error indicates, but the above remarks show at any rate that a very high order of accuracy is required in order to produce effective diffraction gratings. The author proceeded to describe the principles adopted in his machine by which this accuracy is intended to be secured.

Most of the sketches for the machine were made during the years 1876–78. At the close of 1878 the author made an application to the Government Grant Committee of the Royal Society for aid in the construction of the machine, and this being favourably received, the working drawings were put in the hands of Mr. W. R. Munro, of King's Cross Road, in 1879.

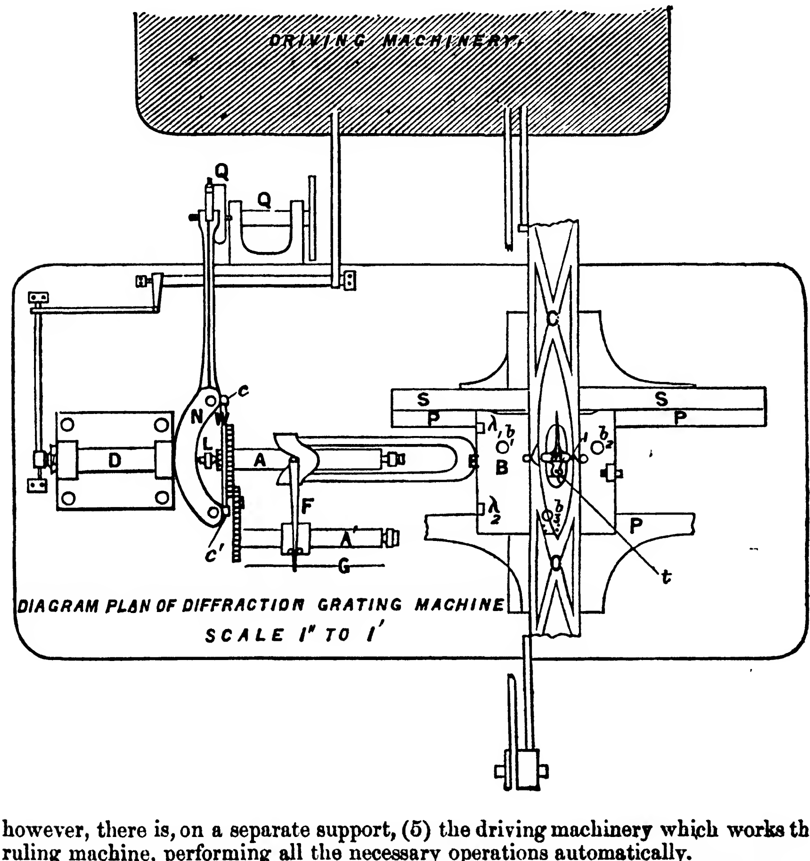
The machine was completed at the close of last year, and some good results have been obtained by it. The chief difficulty experienced, and one which continues to give trouble, is of a very commonplace kind, viz., that of getting a suitable motor, which will go for several weeks without very constant attention, and above

all without stopping, water power unfortunately not being available in the place where the machine has been erected.

Up to the time when this machine was commenced, no diffraction grating had been ruled larger than 2 inches square, and but few as large as this. The new machine was designed to rule 6 inches square, but can if required rule $6\frac{1}{2} \times 6\frac{1}{2}$. Professor Rouland's machine, which seems to have given such good results in America, will, the author believed, rule $6'' \times 4''$.

In describing his ruling apparatus it will be convenient to take the various parts in the following order:—(1) The screw and nut; (2) The platform which supports the grating; (3) The tool carriage; (4) The means employed for turning the screw. These four divisions constitute the ruling machine proper; besides these,

FIG. 1.



however, there is, on a separate support, (5) the driving machinery which works the ruling machine, performing all the necessary operations automatically.

Fig. 1 is a diagrammatic plan of the ruling machine and driving machinery.

I. A perfect screw of any considerable length is a thing which, it has been considered, is almost impossible to produce.

A screw in general has four kinds of errors which are easily measurable. (1) Eccentricity or want of straightness in the axis; (2) Gradual variation of pitch extending over considerable lengths; (3) A periodic variation of pitch of the same length as the pitch of the leading screw of the lathe in which it was cut; (4, which is perhaps the most important), A periodic error which recurs at each thread. In dividing engines, as ordinarily made, the nut is rigidly attached to the platform

which holds the object to be divided, and in this case the first and last-mentioned errors conspire to produce a periodic irregularity in the motion of the platform recurring at each revolution of the screw.

If, however, the nut itself be left free to take any position which it likes, subject only to the condition of not turning round with the screw, the effect of these two errors is to cause the axis of the *nut* to describe a cone about the axis of the *screw*, and the forward motion of the apex of this cone is free from the periodic error in question.

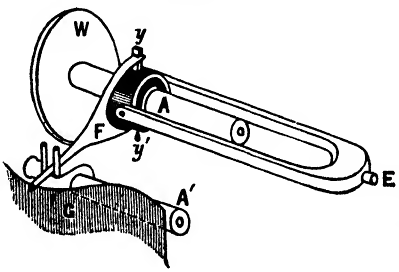
If, then, the nut be held in gymbals, which is in effect to hold it by a point in its axis, and the motion of the nut be communicated to the platform through the gymballing, the error depending on the pitch of the screw does not appear in the motion of the platform.

This plan has been carried out in the ruling machine. Fig. 2 shows a perspective sketch of the screw, nut, gymbals, rings, and pushing piece which connects the nut with the sliding platform.

The pushing piece has a spherical projection at E which fits into a spherical cavity in the end of the platform.

It will be seen that if it were not for the arm F, the nut together with the pushing piece would be capable of turning round with the screw. This arm, which can pivot freely about the axis yy', rests on a guide G, parallel to the axis of the screw, and is continually held at right angles to the screw by means of a pair of jaws, which are carried along by a screw A′, of the same pitch as, and turning simultaneously with, A.

FIG. 2.



If the screw were perfect, the guide on which the ends of the arm F rest ought evidently to be a straight line, but if the errors of the pitch are known, the guide can be so shaped as to make the advance of the nut equal to what it would be if the screw were perfect and the guide straight.

If the nut is more than half as long again as the pitch of the leading screw of the lathe, errors of the third kind will not matter.

It was needless to state in detail the means by which the errors of the screw were measured, but they were made with considerable care, and he did not think any variation in pitch exceeding $\frac{1}{100000}$ inch could have escaped detection.

The screw itself had an error of about $\frac{1}{1000}$ inch in its length, that is to say, at one part the threads were $\frac{1}{1000}$ inch distant from the position which they should have had, had the pitch been uniform throughout.

II. The platform on which the grating rests while being ruled is a plate of cast iron which rests on a plane, P P P, at three points or rather small surfaces, and is touched by a straight edge, S S, at two. This five-point contact ensures motion in a straight line. It will be observed that owing to the method employed to connect the nut and platform, it is not necessary that the direction of motion of the latter should be more than approximately parallel to the axis of the screw.

Through the platform pass three vertically adjustable studs, b_1, b_2, b_3, on which the grating rests, and from one side of the platform one, and from an adjacent side two, cast iron ears, λ_1, λ_2, project, against which the sides of the grating are pressed by screws from the sides opposite.

III. The tool carriage, *c*, fig. 1, which is a very rigid girder of cast iron, is guided much in the same way as the platform.

The tool-holder itself, *m*, is supported on bearings *k*, *k′*, which permit the tool to be raised or lowered on the gratings. The tool, *t*, has besides independent vertical and azimuthal adjustments in the tool-holder.

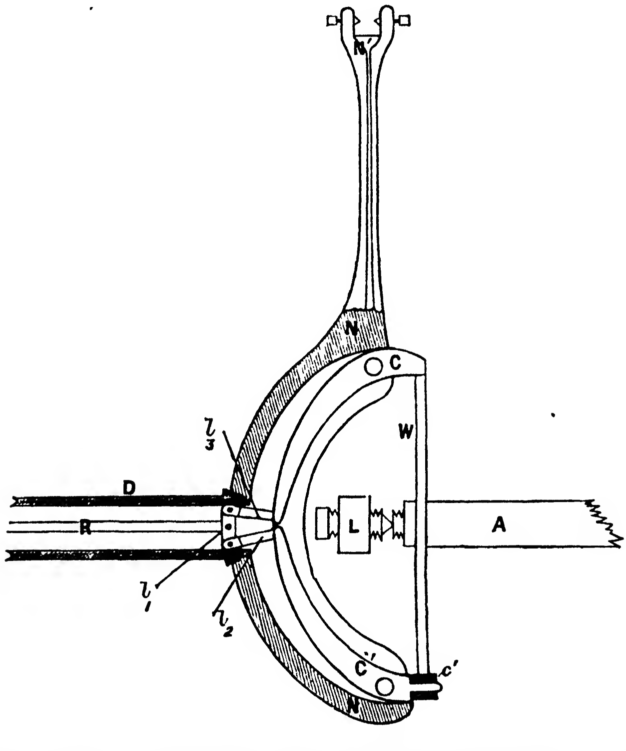
IV. In order to rule lines at equal intervals the screw has to be turned through a constant angle between the ruling of each line.

To effect this the following plan has been adopted with success.

On one end of the screw a wheel, W, six inches in diameter, with a smooth edge, is fixed, and in the continuation of the axis of the screw behind the dead-centre, L, the hollow axis, D, held in rigid bearings bolted on the bed of the machine, carries the iron casting, N. N contains what may be described as an artificial hand, of which the finger and thumb, *c c′*, when tightened, close on a diameter of the wheel W. The end of the lever, N′, is actuated, through a connecting rod, by an adjustable crank, Q, fig. 1, and suitable mechanism removes finger and thumb from the periphery of the wheel during one-half of the revolution of the crank, and tightens them on it during the other half. This causes the screw to turn round by a definite amount at each complete revolution of the crank.

He had now to mention the means employed to make this rotation independent

FIG. 3.



of the various errors of workmanship which are sure to be present in such a contrivance.

In the first place, no strain on the dead-centre support of the screw should result from the pressure of the 'hand,' nor should any slight eccentricity of the wheel affect the amount of the rotation. This is ensured by the arrangement of the levers which open and close the finger, shown in fig. 3. The inner end of the levers, *c c′*, terminate in front of the hollow axis, D. A rod, R, passing through D carries a cross head, l_1, capable of pivoting through a small arc about l_1 in the plane of the levers, *c*, *c′*. Links, l_2 l_3, connect the ends of the cross-head with those of the levers; thus the backwards or forwards movement of the rod, R. in the hollow axis settles the distance between the jaws of *c*, *c′*, but not their absolute lateral position, and the equality of the lengths of the levers and arms of

the cross-head ensure that the forces with which c and c' press on any object nipped between them shall be equal.

Thus any eccentricity of wheel will not prevent both c and c' from acting on it, and since they both press with equal force, no strain will be exerted on the dead-centre support, L.

If the axis of D is absolutely coincident with that of the screw, the angle through which the screw is turned is simply (since, when the hand closes on the wheel, it practically becomes part of it) the arc through which D is turned by the motion of the crank; but suppose the axes are not coincident, but are separated by a distance ϵ, having a component ϵ' in the mean plane of the levers $c\,c'$, the circumferential motion of c is $a(r+\epsilon')$, and of c' $a(r-\epsilon')$, where a is the angular motion given to D by the crank, and small. As both c and c' try to impress their own motion on the rim of the wheel, slipping must occur at one or the other, but at which, if both jaws are made alike, it would be impossible to say. To avoid this uncertainty, c' is made a roller having its axis when closed on the wheel parallel to that of the screw. It then becomes certain that if any slipping occur from the want of coincidence in the axes of D and the screw, it will take place only at c', and the angle through which the screw is turned at each revolution of the crank becomes $a\frac{R}{R-\epsilon}$, where R is the length of N'.

The above description touches on most of the important points in the machine, although there still remain many details and precautions against errors of various kinds, which, though very necessary to the working of the instrument, it would be tedious to describe at length.

The leading objects which the author had in view in making the designs, and which he believed to be very important in all work where a high degree of accuracy is required, were—

1. To supply the necessary and sufficient conditions only to determine the motion of each part.

2. To arrange that, where possible, errors of the first order in the workmanship should only produce errors of the second order in the results.

3. To allow the workman to concentrate his attention on the fulfilment of one condition only to the highest degree of accuracy in each part, and that where one or more other conditions have to be fulfilled by the same part, a lower order of accuracy should be sufficient for them. For instance, in the guidance of the platform which holds the grating, the most important condition is that the straight edge which guides it should be really straight, and this must be fulfilled with the utmost accuracy which good workmanship can attain; it is also requisite that the straight edge should be parallel to the axis of the screw, but this condition, owing to the nature of the connection between the nut and the platform, need only be satisfied approximately.

The action of the driving machinery can best be indicated by the diagram, fig. 4, of the operations which it performs during the ruling of one line. The variety of operations there shown necessarily make the mechanism a little complicated, and the author would only describe that part of it which communicates the reciprocating motion to the tool carriage. The conditions which the reciprocating motion must fulfil are, (1) that the force applied to the tool carriage must be constant in direction; (2) that the velocity should be constant during the whole time that the tool is cutting; (3) that there should be no shock or jerk when the motion is reversed.

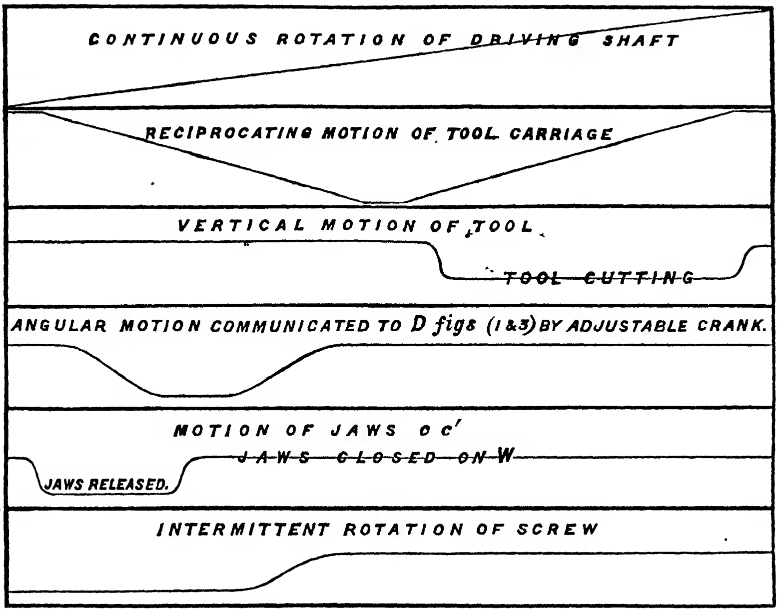
From either end of the tool carriage, fig. 5, steel bands pass over the wheels B c, and that which passes over c is brought back to a wheel B' similar to B, and on the same axis; the axis is fixed, and B and B' revolve independently on it.

Teeth are cut on the flanges of B and B' which gear with those on the larger wheel, D.

D is practically two wheels joined together, rather more than half the circumference of each being bare of teeth. The toothed portions of D engage alternately with B and B'. D, when in gear with B, winds the steel band on to B and off B', and *vice versâ*, the tool carriage being drawn backwards and forwards in the process.

To avoid any shock in starting or reversing, the cams d, b on D and B, which are in reality the halves of a large pair of teeth, have their curves so calculated that, when they engage, D communicates uniform angular acceleration by rolling contact to B, until the velocity of the latter is to that of the former as the pitch

FIG. 4.—Showing the operations performed by the driving machinery while ruling one line of the diffraction grating.



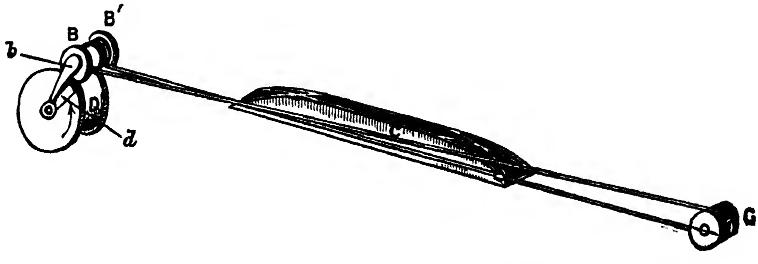
circles of D and B, when the cams separate, leaving the ordinary teeth in gear. There are of course a similar pair of cams on B′ and the opposite side of D.

Cams of the same type are used for starting the intermittent motion which has to be given to the adjustable crank, Q, fig. 1.

The whole of the mechanism has worked without any kind of hitch from the beginning.

As to the results obtained, the author had hitherto, on account of not having a

FIG. 5.



satisfactory motor, confined himself to ruling coarse gratings of from 2,000 to 4,000 lines per inch, the largest which he had ruled up to the present time being about $5\frac{1}{2}$ inches square, with about 2,800 lines per inch. This grating gives very fair results, considering that it is ruled on plate glass not specially worked, but only

picked for uniformity of curvature. Occasionally, with a favourable adjustment, he had divided b_3 with it in the fifth spectrum; to do this the vertical aperture had to be diminished, but not the horizontal.

He did not know what the limit to the closeness of ruling which can be performed by the machine is, but it depends more on the diamond and the surface ruled on than anything else. He had had no difficulty in ruling small areas with 100,000 lines per inch, and although he had no microscope objective which would show lines as close as this, their presence could be detected by the blue gleam of the light diffracted by them when held very obliquely in the sunlight.

At the rate at which he had hitherto worked the machine, viz., about 4 lines per minute, it would take several weeks to rule a 6″ grating of 20,000 lines per inch, and in view of these long periods, during which the temperature of the machine ought not to vary, it has been placed in a double room, one completely enclosed within the other, and apparatus added for automatically keeping the temperature constant.

Self-registering thermometers which record the temperature of the machine room and the outer air show that even when the latter varies from 15° to 18° Fahr., the former does not vary more than two or three tenths; a result which he thought may be considered very satisfactory.

He hoped, however, to be able to increase the speed of working very considerably, the limit to which can of course only be found by trial.

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7. *A Numerical Estimate of the Rigidity of the Earth.* *By* G. H. Darwin, *F.R.S.*

About fifteen years ago Sir William Thomson pointed out that, however it be constituted, the body of the earth must of necessity yield to the tidal forces due to the attraction of the sun and moon, and he discussed the rigidity of the earth on the hypothesis that it is an elastic body.

If the solid earth were to yield as much as a perfect fluid to these forces, the tides in an ocean on its surface would necessarily be evanescent, and if the yielding be of smaller amount, but still sensible, there must be a sensible reduction in the height of the oceanic tides.

Sir William Thomson appealed to the universal existence of oceanic tides of considerable height as a proof that the earth, as a whole, possesses a high degree of rigidity, and maintained that the previously received geological hypothesis of a fluid interior was untenable. At the same time he suggested that careful observation would afford a means of arriving at a numerical estimate of the average modulus of rigidity of the earth's mass as a whole. The semidiurnal and diurnal tides present phenomena of such complexity, that it is quite beyond the power of mathematics to calculate what these heights would be, if the earth's mass were absolutely unyielding. But the tides of long period are nearly free from the dynamical influences which render those of short period so intractable to calculation, and must in fact nearly follow the laws of the 'equilibrium theory.'

In 1867 it was not, however, even definitely known whether or not the tides of long period were of sensible height at any station. Although there has been a continual advance in the knowledge of tidal phenomena since that time, it is only within the last year that there is a sufficient accumulation of tidal observations, properly reduced by harmonic analysis, to make it possible to carry out Sir William Thomson's suggestion. The great advances in knowledge that have been recently made are principally due to the adoption of systematic tidal observation at a great number of stations by the Indian Government. The results of these observations are now being issued yearly by the Secretary of State for India in the form of tide-tables for the principal Indian ports. The author had had the pleasure of carrying out the examination of the tidal records, and a detailed account of the work will appear at § 848 of the new edition of Thomson and Tait's 'Natural Philosophy,' now in the press.

The tides chosen for discussion were the lunar fortnightly declinational tide, and the lunar monthly elliptic tide. These tides must be free from the meteoro-

logical disturbances which make the heights of all the solar tides quite beyond prediction. The fortnightly and monthly tides consist in an alternate increase and diminution of the ellipticity of the elliptic spheroid of which the sea-level (after elimination of the tidal oscillations of short period) forms a part. There are two parallels of latitude, respectively north and south of the equator, which are nodal lines, along which the water neither rises nor falls. When, in the northern hemisphere, the water is highest to the north of the nodal line of evanescent tide, it is lowest to the south of it, and *vice versâ*; and the like is true of the southern hemisphere. If the ocean covered the whole earth the nodal lines would be in latitudes 35° 16′ N. and S. (at which latitudes $\frac{1}{3} - \sin^2 lat.$ vanishes); but when the existence of land is taken into consideration, the nodal latitudes are shifted. Now according to Sir William Thomson's amended equilibrium theory of the tides, the shifting of the nodal latitudes depends on a certain definite integral, whose limits are determined by the distribution of land on the earth's surface.

For the purpose of examining the tidal records, it was therefore first necessary to evaluate this integral. Approximation is of course unavoidable, and for that end the irregular contours of the continents were replaced by meridians and parallels of latitude, and the integral evaluated by quadrature. This procedure will give results quite accurate enough for practical purposes. It appeared as the result of the quadrature that, if we assume the existence of a large antarctic continent, the latitude of evanescent tide is 34° 40′, and if there is no such continent it is 34° 57′. Hence the displacement of the nodal latitudes due to the existence of land is very small.

This point having been settled, the mathematical expressions for the fortnightly and monthly tides are completely determinate, according to the equilibrium theory, with no yielding of the earth's mass.

If there is yielding of the earth, either with perfect or imperfect elasticity, and with frictional resistance to the motion of the water, the height of tide and the time of high-water must depart from the laws assigned by the equilibrium theory. This conclusion may also be stated in another way, which is more convenient for practical purposes; for we may say that at any station there must actually be a tide with a height equal to some fraction of the full equilibrium height and with high-water exactly at the theoretical time, and a second tide, of exactly the same nature, with a height equal to some other fraction of the equilibrium height, but differing in the time of high-water by a quarter-period from the theoretical time—viz. about three-and-a-half days for the fortnightly and a week for the monthly tide. These two tides may, according to geometrical analogy, be called perpendicular component tides. According to the theory of the composition of harmonic motions, the two components may be compounded into a single tide, with time of high-water occurring within a half-period of the theoretical time; and this is the way in which the results of elastic yielding and frictional resistance were first stated above. Thus the actual tide at any station involves two unknown fractions, x and y, being the factors by which two components, each of the full theoretical height, are to be multiplied in order to give the two components in proper amount to represent the reality.

If the equilibrium theory is fulfilled without sensible elastic yielding of the earth, the first component has its full value, or x is equal to one, and the second component vanishes, or y is zero. If fluid friction exercises a sensible influence, y will have a sensible value; and if the solid earth yields tidally, x will be less than unity. The amount of elastic yielding, and hence the average modulus of elasticity of the whole earth may be computed from the value of x. After rejecting the observations made at certain stations for sufficient reasons, the author obtained from the Tidal Reports of the British Association and from the Indian Tide Tables, the results of thirty-three years of observation, made at fourteen different ports in England, France, and India.

These results, when properly reduced, gave thirty-three equations for the x and thirty-three for the y of the fortnightly tide, and similarly thirty-three for the x and thirty-three for the y of the monthly tide; in all 132 equations for four unknowns.

The x and y of the two classes of tide were in the first instance regarded as distinct, but the manner in which they arise shows that it is legitimate to regard them as identical, and thus we have sixty-six equations for x and sixty-six for y.

The equations were then reduced by the method of least squares, with the following results:—

For the fortnightly tide—

$$x = \cdot 675 \pm \cdot 056, \; y = \cdot 020 \pm \cdot 055.$$

And for the monthly tide—

$$x = \cdot 680 \pm \cdot 258, \; y = \cdot 090 \pm \cdot 218.$$

The numbers given with alternative signs are the probable errors.

The very close agreement between the x and y for the two tides is probably somewhat due to chance.

The smallness of the two y's is satisfactory; for, as above stated, if the equilibrium theory were true, they should vanish. Moreover, the signs are in agreement with what they should be, if friction is a sensible cause of tidal retardation. But considering the magnitude of the probable errors, it is of course more likely that the non-evanescence of the y's is due to errors of observation or to the method of reduction.

The author had already submitted to the British Association at this meeting a paper on a misprint, discovered by Professor Adams, in the Tidal Report for 1872. This report forms the basis of the method of harmonic analysis which has been employed in the reduction of the tidal observations, and it appears that the erroneous formula has been systematically used. The large probable error in the value of the monthly tide may most probably be reduced by a correct treatment of the original tidal records.

It has been already remarked that it is legitimate to combine all the observations together, for both sorts of tide, and thus to obtain a single x and y from sixty-six years of observation. Carrying out this idea he found:—

$$x = \cdot 676 \pm \cdot 076, \; y = \cdot 029 \pm \cdot 065.$$

These results really seem to present evidence of a tidal yielding of the earth's mass, and the value of the x is such as to show that the effective rigidity of the whole earth is about equal to that of steel.

But this result is open to some doubt for the following reason:—

Taking only the Indian results (forty-eight years in all), which are much more consistent than the English ones, he found

$$x = \cdot 931 \pm \cdot 056, \; y = \cdot 155 \pm \cdot 068.$$

We thus see that the more consistent observations seem to bring out the tides more nearly to their theoretical equilibrium values with no elastic yielding of the solid.

It is to be observed however that the Indian results being confined within a narrow range of latitude give (especially when we consider the absence of minute accuracy in his evaluation of the definite integral) a less searching test for the elastic yielding than a combination of results from all latitudes.

On the whole we may fairly conclude that, whilst there is some evidence of a tidal yielding of the earth's mass, that yielding is certainly small, and that the effective rigidity is at least as great as that of steel.

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8. *On the Transmission of Force through an Elastic Solid. By* Professor Sir WILLIAM THOMSON, *F.R.S.*

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9. *On a Method of investigating Magnetic Susceptibility. By* Professor Sir WILLIAM THOMSON, *F.R.S.*

WEDNESDAY, AUGUST 30.

The following Papers were read:—

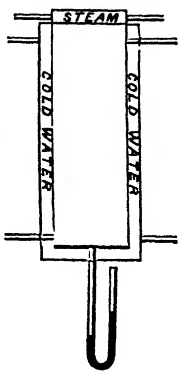
1. *On a Method of investigating experimentally the Absorption of Radiant Heat by Gases. By* Professor TAIT, *Sec. R.S.E.* (From a letter to Sir W. Thomson).

There are grave objections, which have been only partially overcome, to almost all the processes hitherto employed for testing the diathermancy of vapours. These arise chiefly from condensation on some part of the apparatus. Thus when rock-salt is used, an absorbent surface-layer may be formed; and, when the pile is used without a plate of salt, the effect of radiant heat may be to cool it (the pile) by the evaporation of such a surface-film.

Some time ago it occurred to me that *this* part of the difficulty might be got rid of by dispensing with the pile, and measuring the amount of absorption by its effects on the volume and pressure of the gas or vapour itself.

Only preliminary trials have as yet been made. They were carried out for me by Professor MacGregor and Mr. Lindsay. Their object was, *first,* to find whether the method would work well; *second* (when this was satisfactorily proved), to find the best form and dimensions for the apparatus.

The rough apparatus is merely a double cylinder, placed vertically. Cold water circulates in the jacket surrounding the curved surface and bottom, and steam can be blown into the double top. The changes in the pressure of the gas are shown by a manometer U-tube at the bottom, which contains a liquid which will not attack the contents.



This apparatus was four feet long, with two inches' radius. The results of a number of experiments show that it should be shorter and much wider. The former idea I was not quite prepared for; the latter is obvious.

The effects on the manometer are due to five chief causes:—

1. Heating of the upper layer of gas by contact with lid.
2. Cooling of the upper layer of gas by contact with sides.
3. Heating of more or less of the column by absorption.
4. Cooling of more or less of the column by radiation.
5. Cooling of more or less of the column by contact.

1 and 2 only are present in a perfectly diathermanous gas, as well as in a perfectly adiathermanous gas or vapour; all five take place simultaneously in a partially diathermanous gas or vapour.

The preliminary experiments show that the manometer effect is only *very slightly less* for dry olefiant gas than for dry air, while moist air shows a markedly smaller effect than either of the others.

This is conclusive as to the absorption of low radiant heat by aqueous vapour, but it shows also that the absorption is so small as to take place throughout the whole column.

Even with the present rude apparatus I hope soon to get a very accurate determination of the absorbing power of aqueous vapour, by finding in what proportions olefiant gas must be mixed with dry air to form an absorbing medium equivalent to saturated air at different temperatures.

I have to acknowledge valuable hints from Professor Stokes, who, before I told him the results I had obtained (thus knowing merely the *nature* of the experiments), made something much higher than a guess, though somewhat short of a prediction, of the truth.

In these preliminary trials no precaution was taken to exclude *dust*. The results, therefore, are still liable to a certain amount of doubt, as Mr. Aitken's beautiful experiments have shown.

The *point* of the method is that there can be no question of surface-layers, provided the operation be carried on long enough.

2. *On Atmospheric Electricity.*[1] *By* Professor C. MICHIE SMITH, *B.Sc., F.R.S.E.*

3. *On the Alteration in the Dimensions of the Magnetic Metals by the Act of Magnetisation. By* Professor W. F. BARRETT, *F.R.S.E.*

In 1842 Dr. Joule discovered that when a bar of iron was magnetised by an electric current an *elongation* of the bar took place. In subsequent experiments, published in 1847, Joule found that the elongation amounted to about $\frac{1}{200,000}$th of the length of the bar for the maximum magnetisation, and that the total elongation was nearly proportional to the square of the actual magnetisation. By placing the bar in a vessel of water stopped with a capillary tube it was found that the volume of the iron did not augment, and hence Joule concluded that the sectional area diminished in proportion to the elongation. Under longitudinal tension magnetisation caused a *shortening* of the rod when the tension exceeded 600 lbs. for a rod a quarter of an inch square. Soft steel behaved like iron; but hard steel, under all circumstances, Joule found to shorten slightly when the magnetising current passed.

In 1873 Professor Mayer repeated Joule's experiments with new and delicate apparatus; the elongation of the iron he found to amount to $\frac{1}{277,000}$ of its length for the maximum magnetization. Mayer also found that soft as well as hard steel contracted under magnetisation.

In the same year the author made a series of experiments on the other magnetic metals, nickel and cobalt, and found that whilst cobalt lengthened under magnetisation, nickel appeared to suffer no change.[2] This result is surprising, for nickel more nearly resembles iron and cobalt than steel in magnetic properties, the former having little coercive force and the latter very considerable retentive power. With entirely new apparatus the experiments were repeated and a distinct *shortening* of the nickel was now found, cobalt elongating, but not so much as iron. The multiplying apparatus that was found to yield most satisfactory results was a simple form of optical lever, a mirror vertically fixed over the fulcrum of a lever of the first order and reflecting a scale at some distance into an observing telescope. The apparatus will be more fully described in the report that will be presented next year, a committee, with a small money grant, having been appointed at a previous meeting of the Association to investigate this and certain other molecular changes accompanying the magnetisation of iron described by the author at the Bradford meeting of the Association.

The results so far obtained may be summed up as follows:—However often the current traverses the helix around the bar of *cobalt*, the elongation is practically the same after the first current, and amounts to about two-thirds of the elongation produced in an iron bar of the same dimensions. In my measurements the elongation of the iron amounted to about $\frac{1}{270,000}$ of its length for the maximum magnetisation; the iron elongated 55 scale-divisions and the cobalt 35.

With *nickel*, after the first magnetising current is passed the retraction is practically the same for succeeding currents; with the same scale the nickel retracted 100 divisions, or about double the elongation of iron.

Enclosing the bars in a vessel of water with a capillary tube, having a helix encircling the vessel, no motion of the index was noticed on magnetising the cobalt and the iron, but a slight fall of the index, indicating a diminution of volume, was noticed with nickel. The experiments, however, were somewhat rough, and will shortly be repeated with greater care.

The 'magnetic tick' is heard loudly with cobalt and nickel, as well as iron, the former giving a very clear metallic click on magnetisation.

The author is much indebted to the kindness of Messrs. Johnson and Matthey for the bars of nickel and cobalt ($9\frac{1}{2}$ inches long and 1 inch diameter) with which the

[1] Published in *Proc. Roy. Soc. Edin.* 1881-82.

[2] *Phil. Mag.* January, 1874.

experiments were conducted, and also to Mr. Gore, F.R.S., for the loan of a longer bar of nickel. Experiments are now in progress to determine the effect of temperatures and longitudinal tension on the results.[1]

4. *On an Instrument for measuring the Intensity of Aërial Vibration.*[2] *By* Professor Lord Rayleigh, *F.R.S.*

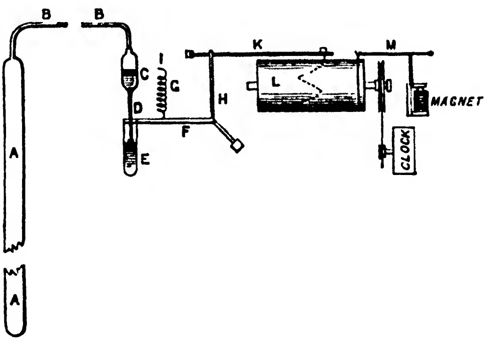
5. *On the Effect of Wind on the Draught of Chimneys.* *By* Professor Lord Rayleigh, *F.R.S.*

6. *On a Mechanical Self-registering Thermometer.* *By* A. Mallock.

Having recently had occasion to keep a room at a constant temperature for many days together, the author had, in order to test the efficiency of the apparatus employed for that purpose, to have some means of continuously recording the temperature of the room and also of the external air.

Several causes prevented the use of the ordinary photographic method, and he therefore designed the mechanical recording thermometer which is the subject of this communication; and since there are obvious advantages in dispensing with photography if equally accurate results can be obtained by a simple mechanical means, and as the same principles can be applied to the construction of a mechanical self-recording barometer, he hopes the short description of his apparatus, which will be given here, may not be without some use.

The thermometer consists of a long glass bulb (A) holding about half a pint of spirits of wine. This bulb is connected by a fine metallic tube (B), also full of spirit, with a small bulb (C) near the recording apparatus. C is half-full of mercury and half of spirit, and terminates in a capillary tube (D), which dips into a deep



cup (E), which also contains mercury. This cup is suspended from a horizontal lever (F), and its weight, without the mercury, counterbalanced.

The weight of the mercury in the cup is taken by the spiral spring (G).

The upright arm (H), attached to the lever, carries the pen-rod (K), which marks on the horizontal cylinder (L).

The cylinder turns round once a week, and time is marked on the paper at intervals of three hours by a pen (M) actuated by an electro-magnet through which currents are sent at the desired intervals by a contact-maker on the clock.

The effect of a change of temperature is to expel or suck mercury from or into the small bulb, and the variation of weight on the spiral spring is the same as it would have been had the large bulbs been filled with mercury, and mercury had the coefficient of expansion of spirits of wine.

[1] For a fuller report of this paper, see the *Electrician* for October 14, 1882.

[2] *Phil. Mag.* September, 1882.

The cup (E) must be so shaped that the end of the capillary tube (D) never emerges from the surface of the mercury in the cup, and that this may be the case the descent of the cup due to the introduction of a given quantity of mercury should not be greater than the height which the mercury introduced occupies in the cup; or, in symbols, if σ is the area of the cup, l the unstretched length of the spiral spring, and a the volume of mercury required at (D) to stretch it to double its natural length,

then $$\sigma = \pi < \frac{a}{l}$$

It will be seen that, by taking a properly proportioned spring and cup, the thermometer may be made to record to any desired scale; but the limit to the accuracy of the record is of course fixed (for any given thermometer) by the constant friction of the moving parts. This, however, can without trouble be made very small.

To apply the mechanical method to the barometer it is only necessary to hang the barometer tube to the lever (F) instead of the cup (E), allowing the open end to dip into a deep fixed cistern.

The greatest part of the weight of the mercury in the tube should of course be counterbalanced, leaving only the variable part to be taken by the spring. The variation of the barometer alters the extension of the spring by a quantity directly proportional to the variation of the weight of the column of mercury supported; thus the curve drawn by this kind of self-recording barometer requires no correction for temperature, except a small term depending on the expansion of the glass. The rise or fall of the tube in the mercury cistern gives rise to a force depending on the flotation of the immersed part of the glass tube; but as this force is a linear function of the rise or fall, it makes no difference in the character of the curve traced by the instrument, and is equivalent merely to an alteration of the value of (a) which measures the stiffness of the spring.

7. *On a Musical Instrument.* *By* J. PHILIPS.

8. *On an Arithmetical Model.* *By* Sir F. J. BRAMWELL, *F.R.S.*

Section B.—CHEMICAL SCIENCE.

President of the Section—Professor G. D. Liveing, M.A., F.R.S., F.C.S.

THURSDAY, AUGUST 24.

The President delivered the following Address:—

If I were asked in what direction chemical science had of late been making the most important advances, I should reply that it was in the attempt to place the dynamics of chemistry on a satisfactory basis, to render an account of the various phenomena of chemical action on the same mechanical principles as are acknowledged to be true in other branches of physics. I cannot say that chemistry can yet be reckoned amongst what are called the exact sciences, that the result of bringing together given matters under given circumstances can yet be deduced in more than a few special cases by mere mathematical processes from mechanical principles, but that some noteworthy advances have in recent years been made, which seem to bring such a solution of chemical problems more nearly within our reach.

To show how large a gap in our ideas of chemical dynamics has been bridged over within the last quarter of a century, I will quote the words of one of the largest-minded philosophers of his time, who was one of the earliest promoters of this Association, and its President in 1841: Whewell, in a new and much altered edition of his 'Philosophy of the Inductive Sciences,' published in 1858, says:—'Since Newton's time the use of the word *attraction*, as expressing the cause of the union of the chemical elements of bodies, has been familiarly continued, and has no doubt been accompanied in the minds of many persons with an obscure notion that chemical attraction is in some way a kind of mechanical attraction of the particles of bodies. Yet the doctrine that *chemical* 'attraction' and *mechanical* attraction are forces of the same kind has never, so far as I am aware, been worked out into a system of chemical theory; nor even applied with any distinctness as an explanation of any particular chemical phenomena. Any such attempt, indeed, could only tend to bring more clearly into view the entire inadequacy of such a mode of explanation. For the leading phenomena of chemistry are all of such a nature, that no mechanical combination can serve to express them without an immense accumulation of additional hypotheses.' ('History of Scientific Ideas,' ii. 13.) And further on he says:—'We must consider the power which produces chemical combination as a peculiar principle, a special relation of the elements not rightly expressed in mathematical terms.' (*Ibid.* p. 14.)

The influence by which our ideas have gone round so as to be now the very opposite of those of the illustrious thinker whom I have just quoted, so that we should ridicule the thought of looking for an explanation of chemical action on any but mechanical principles, is undoubtedly the progress which has been made in other branches of molecular physics. The indestructibility of matter has long been a formula familiar to chemists, but that the conservation of energy should be as universally true, even in regard to chemical actions, has only in recent years been fully recognised. This is certainly no new principle, it was developed mathematically generations ago; but the realisation that it is anything more than an abstraction, that it is the keynote of every rational explanation of physical phenomena, has been the foundation of recent progress in physical science; and if all energy be one, there can be but one code of dynamical laws, which must apply to chemistry as well as to all other branches of physics. The development of the mechanical

theory of heat, and of the molecular theories which have grown up in consequence of it, have done much to set our minds free from preconceived notions, and to induce us to build chemical theories on something more than unverified conjectures.

But how far can we say that mechanical principles are actually recognised as the true basis of rational chemistry? So far as I know no chemist denies that it is so, and yet how little do our text-books, even the most recent and the most highly reputed, show the predominance of this idea! How very small a portion of such books is taken up with it, how much seems utterly to ignore it or to be couched in language antagonistic to it! We still find chemical combinations described as if they were statical phenomena, and expressions used which imply that two perfectly elastic bodies can, by their mutual action alone, bring each other into fixed relative positions. We still find change of valency described as a suppression of 'bonds of affinity,' as if a suppression of forces were the usual course of nature, or as if it were possible that the same two forces, acting at the same place and in the same direction, should at one time neutralise one another, and at another time not neutralise one another. We still find saturated compounds spoken of as if the stability of a compound were independent of circumstances, and chemical combination no function of temperature and pressure. Beginners are sometimes helped by the invention of intermediate reactions in explanation of final results, without any reference to the dynamical conditions of the problem, without any consideration whether the fancied intermediate reactions imply a winding-up or a running-down of energy. In fact our long familiar chemical equations represent only the conservation of matter, and to keep always in mind the mechanical conditions of a reaction is as difficult to some of us as it is to think in a foreign language. Moreover, we still find in many of our text-books the old statical notion of chemical combination stereotyped in pictures of molecules. I do not, of course, mean to accuse the distinguished inventors of graphic formulæ of meaning to depict molecules, for I believe that they would agree with me in thinking that these diagrams do not any more nearly represent actual molecules than they represent the solar system; but unfortunately we cannot prevent beginners from regarding them as pictures, and moulding their ideas upon them. They present something easily grasped by the infant mind, and schoolmasters are fond of them; but only those who have each year to combat a fresh crop of misconceptions, and false mechanical notions engendered by them, can be aware how much they hinder, I won't say the advance, but the spread of real chemical science. If it be true that the illustrations of an artist like the late Hablot Browne give to our conceptions of the characters of a story a more definite and permanent, though perhaps a much modified form of what the author of the story intended to portray, it is equally true that the illustrations by which some, even great names amongst us, have tried to make us fancy that we had a true conception of some natural process, have become so fixed in our minds as to prevent our realising the true meaning of nature.

What, then, is the progress which I think has been made in physical chemistry? In the first place, notwithstanding the slowness with which new ideas replace old familiar images, the molecular theories developed by Clausius, Clerk Maxwell, and Boltzmann, and by Sir W. Thomson, have been long enough before the world to have greatly loosened the hold upon our minds of many old notions. The rigid, unbreakable, impenetrable atoms of the Epicurean philosophy, made familiar to us by Lucretius, always presented difficulties which were only perhaps exceeded by those of the elastic atmospheres with which modern philosophers fancied them to be surrounded; but now the vortex theory, whether we think it probable or not, at least gives us a standing ground for the assertion that the supposed impenetrability of matter, and the curious compound of nucleus and atmosphere which had been invented to account for elasticity, are not necessary assumptions.

The kinetic theory of gases has analysed for us the different motions of the molecules in a mass of matter, and has facilitated the conception of the part which heat plays in chemical action. Hence we have had of late several attempts to reduce to a form susceptible of mathematical calculation the problems of chemistry. Most of these attempts have proceeded on the well-known mechanical principle

that the change of *vis viva* of a system, in passing from an initial to a final configuration, is independent of the intermediate stages through which it may have passed provided the external conditions are unaltered; and on the principle of the dissipation of energy, that is to say, on the condition that the state of the system, if it be a stable one, must be such that the energy run down in reaching it is a maximum. These principles have been applied successfully to the solution of some particular cases of the equilibrium between a mixture of chemicals by Willard Gibbs, Berthelot, and others. By the first-mentioned principle all consideration of the intermediate stages by which the final result is reached is avoided. Quite recently Lemoinne has attacked the same problem on another principle. His principle is that of an equilibrium of antagonistic reactions in a mixture of materials, a mobile equilibrium, such as we are now familiar with, dependent on compensating effects; but he does not seem able to solve the problem in any great number of cases. In fact, the difficulty does not now lie so much in expressing mathematically the conditions of the problem, as in the defect of knowledge which depends upon experiment. And it is just in this that I think the outlook most hopeful. In some cases the patient work of weighing, measuring, and comparing, which is necessary to make our theoretic speculations of any substantial value, has been already done for us. The publication, three years since, of Berthelot's 'Essay on Chemical Mechanics,' has given us, in a collected form, a large quantity of data of the first importance, and now I am glad to say that the long labours of another worker in the same field, Thomsen of Copenhagen, are in course of publication in a handy form. I think these two investigators have done more than anyone else of late years towards making it possible to give chemistry the rank of an exact science. But besides the data which they have supplied to us, there are others which are yet wanting. For instance, almost every equation of chemical equilibrium involves an expression depending on the specific heat of the materials. At present we do not know enough of the law of specific heats to be able to give in most cases a probable value to these expressions, but these and other data of the kind do not seem out of our reach, and we may hope that the same ingenuity and patience which have gained for us so much firm ground in thermal chemistry will extend it to the uncertain spots where we have as yet no solid foundation.

Further, the laws of dissociation, so ably investigated by Deville, have taught us that the force called chemical affinity, by which we suppose the atoms of unlike matters are held together in a compound molecule, follows precisely the same laws as the force of cohesion by which particles of a similar kind are united in molecules. We have long known that the molecules of sulphur vapour are broken up into simpler molecules by elevation of temperature, and condense again when the temperature is reduced. Other elementary substances behave in a similar way. We have within the last two or three years learnt that iodine is in part dissociated by a high temperature from molecules consisting of two chemical atoms into molecules consisting of only one such atom, and the same is true of chlorine and bromine. That some such change must occur in iodine was inferred as long ago as 1864 by the younger Mitscherlich. He argued that iodine is a compound body from the fact that it shows two spectra, one similar in character to those of metallic oxides and the other similar to the spectra of metals, and from the analogy in the behaviour of iodine to a metallic oxide in giving the one spectrum at one temperature and the other at a higher temperature: 'from this,' he says, 'it would follow that iodine at ordinary temperatures and iodine at the temperature of a hydrogen flame must be considered as two different compounds, because the spectrum of iodine formed at ordinary temperatures' (that is, the absorption spectrum of iodine vapour) 'is different from that produced in a hydrogen flame.' Also 'that bromine, though it gives no flame spectrum, gives one spectrum by absorption and another by the electric spark, and must therefore in its ordinary state be regarded as a compound.' Also that 'the spectra formed by the flames of selenium, tellurium, and phosphorus, and those of sulphur and nitrogen given by feeble electric discharges, all have the character of the iodine flame spectrum, and these metalloids would therefore, if the above expressed supposition with regard to iodine be confirmed, also be compound bodies.' ('Phil. Mag.' 1864, p. 188.) Since the paper from which the foregoing extract is

taken was published, not only the metalloids but many metals have been found to give complicated spectra at one temperature and much simpler spectra at higher temperatures. Such are the channelled spectra of sodium and potassium, first described by Roscoe and Schuster, the channelled spectra of silver, bismuth, and other metals described by Lockyer and Roberts, and the ultra-violet channelled spectrum of tin recently photographed by Dewar and myself. Mitscherlich's hypothesis gives us a rational explanation of such multiple spectra produced by the same substance, and it has been accepted, in one form or another, by all spectroscopists since he wrote. Nevertheless, the existence of multiple spectra cannot be taken as a proof of allotropic modification unless the possibility of a chemical combination be excluded. The channelled spectrum which magnesium gives in hydrogen was mistaken by more than one observer for that of some modification of the simple metal, until it was shown that magnesium in nitrogen or other gases does not give it if no hydrogen is present, and that its persistence in hydrogen at high temperatures depends, as does the permanence of chemical combinations, on the pressure of the gas. If, however, homogeneous molecules are dissociated by heat, so also are heterogeneous molecules, formed, as we say, by chemical combination, split up by elevation of temperature, to unite again on cooling, or when the pressure is increased within certain limits. Nor is there any essential difference in character between a chemical compound and an element beyond that of facility of decomposition. If we could not so easily resolve them into their constituents, and were to disregard the difference of their spectra, no one would suppose ammonia to be differently constituted from potassium, or cyanogen from chlorine. Indeed, chemists have long been in the habit of considering the union of two atoms in a molecule of ordinary hydrogen or chlorine as a species of chemical combination; but when we find that the combinations of particles of the same kind are as definite as those of particles of different kinds, and that they are both subject to precisely the same mechanical laws, we are hardly justified in regarding the forces by which they are produced as essentially different. To get rid of a gratuitous hypothesis in chemistry must be a great gain.

But it may be asked, why stop here? Why may not the chemical elements be further broken up by still higher temperatures? *A priori* and from analogy such a supposition is extremely probable. The notion that there is but one elementary kind of matter is at least as old as Thales, and underlies Prout's hypothesis that the atomic weights of our elements are all multiples of that of hydrogen. This famous hypothesis has gone up and down in the scale of credibility many times during the present century. About seventeen years ago the publication of Stas' new determinations of combining weights, carried out on a scale never before attempted, and with all the refinements which the growth of our knowledge could suggest, was thought to have given it its death-blow. But a reaction has set in since that time. The periodic recurrence of the properties of elements with regular additions to the atomic weights, like octaves in a musical scale, put forcibly before us by Mendelejeff, makes it difficult not to think that there is a simple relation between the atomic weights, though there may be causes producing slight perturbations of such a relation. Quite recently a fresh revision of the combining weights has been made on the other side of the Atlantic by Professor F. W. Clarke. He has collected all the determinations made by different observers, and after rejecting such as from defective methods were untrustworthy, has applied to the remainder such corrections as newer experiences have suggested, and then deduced from the corrected numbers the most probable values by the methods of the theory of errors. Professor Clarke has done a piece of work of the highest utility, for which chemists must be grateful; nevertheless, he has not carried the revision so far as it might be carried. He has, to begin with, rightly separated the several sets of observations, and deduced the most probable number from each set by itself, but in combining the various sets for the final determination of the numbers adopted, he has treated the results obtained by different methods as if they were a set of observations all presumably of equal value, so that the most probable numbers could be deduced by the method of least squares. He has not attempted any discussion of the different methods with a view to an estimate of the relative values of the results

obtained by them, nor made any difference between the values of the figures deduced from operations on the large scale employed by Stas and those arrived at on the small scale of other observers. Any sort of handicapping of methods is no doubt a very difficult and delicate operation, and requires more than the judgment of an Admiral Rous, but without it the question whether the numbers adopted are the best obtainable will always be an open one. It is, however, a very noteworthy fact, that in almost every case the numbers deduced from Stas' experiments, taken by themselves, coincide very closely indeed with the most probable numbers derived by the method of least squares from the whole of the recorded estimates. On the whole, Professor Clarke concludes that Prout's hypothesis, as modified by Dumas, is still an open question, that is to say, his final numbers differ from whole multiples of a common unit by quantities which lie within the limits of errors of observation and experiment.

Let us turn again to the evidence afforded by our most powerful instrument for inspecting the inner constitution of matter, the spectroscope. A few years ago Mr. Lockyer supposed that the coincidence of rays emitted by different chemical elements, particularly when those rays were developed in the spark of a powerful induction coil and in the high temperatures of the sun and stars, gave evidence of a common element in the composition of the metals which produced the coincident rays. Such an argument could not be drawn from the coincidences unless they were exact, and the identity of the lines could only be tested by means of spectroscopes of great resolving power. By the use of the well-known Rutherford gratings, Young in America had found that most of the solar lines which had been ascribed to two metals were in reality double, and Dewar and I, working on the terrestrial elements in the electric arc, had found the actual coincidences to be very few indeed. These observations, even with Rutherford gratings, were delicate enough; but quite recently M. Fievez, of the Brussels Observatory, has brought to bear on this question a spectroscope of unexampled power. By combining two of the Astronomer Royal's highly dispersive half-prisms with a Rutherford grating of 17,296 lines to the inch, he has obtained a dispersion quadruple—that of Thollon's combination of prisms. Bringing this to bear on the sun he has mapped the solar spectrum from a little below C to somewhere above F, on a scale one-third greater than that of Vogel's map, and has not only confirmed the work of Young, Dewar, and myself, but has resolved some lines which were not divisible by such dispersive power as we had at command. This result cannot fail to shake our belief, if we have any, in the existence of any common constituent of the chemical elements; but it does not touch the evidence which the spectroscope affords us, that many of our elements, in the state in which we know them, must have a very complex molecular structure. I cannot illustrate this point better than by the spectra of two of our commonest elements, magnesium and iron. We have good reason to think the molecule of magnesium to be as simple as that of any chemical element, and we find its spectrum to be one of the simplest, consisting of a series of triplets which repeat each other in a regular way and are probably harmonically related, and of a comparatively small number of single lines, of which also some may be harmonics. The spectrum of iron, on the other hand, presents thousands of lines distributed irregularly through the whole length, not only of the visible, but of the ultra-violet region. Make what allowance you please for unknown harmonic relations, and for lines which are not reversible and may not be directly due to vibrations of the molecules, we still have a number of vibrations so immense that we can hardly conceive any single molecule to be capable of all of them, and are almost driven to ascribe them to a mixture of differing molecules, though we have as yet no independent evidence of this, and no satisfactory proof that any of this mixture are of the same kind as occur in other elements.

M. Fievez's combination is a great advance in resolving power, but Professor Rowland, of the John Hopkins University, promises us gratings not only exceeding Rutherford's both in dimensions and accuracy of ruling, but ruled upon curved surfaces so as to dispense with the use of telescopes and avoid all variations in focussing the different orders of spectra. His instruments, if they come up to the

promise he holds out, will enable us to solve many questions which are difficult to answer with our present appliances.

But to return to the chemical elements: the spectroscope has in the last few years revealed to us several new metals. I will not venture to say how many, for when several new metals more or less closely allied are discovered at the same time, the process of sifting out their differences is necessarily a slow one. We cannot tell yet whether any of them are to fill gaps in Mendelejeff's table, and so add strength to the conviction that there is a natural relation between the atomic weights and the chemical characters of our elementary substances, or whether they will add to the embarrassment in which we already find ourselves with regard to the relations of the cerium group of metals; whether we may welcome them as the supporters of order, or deprecate their coming as authors of confusion. Granting that the chemical characters of an element are connected with its atomic weight, we have, however, no right to assume them to be dependent on that factor alone. Why may there not be elements which, while they differ as little in atomic weight as do nickel and cobalt, are, on the other hand, so similar to one another in all characters that their chemical separation is a matter of the greatest difficulty, and their difference only distinguishable by the spectroscope? The spectra may be thought to suggest so much, and how shall we decide the question? At any rate the complications of the spectroscopic problem can only be unravelled by the united efforts of the chemists and physicists, and by the exercise of extreme caution.

I cannot dismiss the subject of chemical dynamics without alluding to the ingenious theory by which the President of the Association has proposed to account for the conservation of solar energy. He supposes planetary space to be pervaded by an atmosphere which, except where it is condensed by the attraction of the sun and planets, is in a highly attenuated state. The sun and planets communicate some of their own motion of rotation to the atmosphere condensed about them, and he supposes that in this way an action like that of a blowing fan is set up, by which the equatorial part of the sun's atmosphere acquires such a velocity as to stream out to distances beyond the earth's orbit, while an equal quantity of gas is drawn in at the poles to maintain equilibrium. The gases thus driven to a distance in planetary space will of course be enormously expanded and highly attenuated, and in this state Dr. Siemens thinks that such of them as are compound may be decomposed by absorbing the solar radiation, and thus the kinetic energy of the sun's rays be converted into the potential energy of chemical separation. The separated elements, or partial compounds, will in the circulation produced by the fanlike action of the solar rotation be carried back to the polar regions of the sun as fuel to maintain his temperature by condensation and re-combination. I will not discuss the mechanical part of this theory further than to remark that the fanlike action can only be carried on at the expense of the energy of the sun's rotation, which must in consequence be continually diminishing, and must in time become too slow to produce any sensible projection of the atmosphere into distant regions of planetary space. As to the chemical side of the theory, Dr. Siemens supposes the gases which pervade the planetary space to be not only of the same kind as the components of our own atmosphere, which on the kinetic theory of gases must diffuse through that space, but also such gases as are not found in our air, but are found occluded in meteorites, which may be supposed to have acquired them in their previous wanderings. Amongst these he specially mentions hydrocarbons which form the self-luminous part of most comets. It is to these gases, together with aqueous vapour and carbonic acid, that he ascribes the principal part in the conservation of solar energy. That compound gases at the extremely low pressure of the planetary space are decomposed by solar radiation is not inconsistent with the laws of dissociation, for it is quite possible that some compounds may be decomposed at ordinary temperatures by mere reduction of pressure, and the radiation absorbed will be the more effective because it will directly affect the vibratory motion within the molecule, and may well produce chemical decomposition before it can, when the free path of the molecules is so much increased by the attenuation of the gas, assume the form of an increased temperature. Dr. Siemens, moreover,

adduces a remarkable experiment in confirmation of this supposition. We know, too, the power which our atmosphere, and especially the water vapour in it, has of absorbing the infra-red rays, and that amongst the Fraunhofer lines some of the strongest groups are due to aqueous vapour; and the capital observation made by the spectroscopic observers at the last total eclipse, that the group of lines known as 'B,' which is one of those produced by aqueous vapour, is greatly strengthened when the sun's light passes by the edge of the moon and so through the lunar atmosphere, may be taken as a confirmation of the theory that gases like our atmosphere are diffused through space and concentrated about the planets. But if it be true that the compounds are decomposed by absorbing the sun's rays, we ought to find in our atmosphere the products of decomposition, we ought to find in it free hydrogen, carbonic oxide, and acetylene or some other hydrocarbons. The hydrogen, from its small specific gravity, would not be concentrated in the lower regions of our atmosphere in the same proportions as the denser gases, but carbonic oxide and hydrocarbons could not fail to be detected in the air if they formed any sensible proportion of the gases in the planetary space. That a large portion of solar radiation is intercepted before it reaches the earth is no doubt true, for there are not only the dark bands which are increased by our atmosphere and may reasonably be attributed to the action of like gases pervading planetary space, but there is a continuous absorption of the ultra-violet spectrum beyond the line U, and Cornu has found that this absorption is not sensibly affected by our atmosphere, so that the substance, whatever it be that produces it, may be an agent in the process imagined by Dr. Siemens, but cannot be the means of restoring to the sun any portion of his radiant energy which reaches our distance from him.

Dr. Siemens explains the self-luminous character of comets by the theory that the streams of meteoric stones of which they are supposed to consist bring from stellar space hydrocarbon and other gases occluded within them, and that in consequence of the rise of temperature due to the frictional resistance of such a divided mass moving with enormous velocity, aided by attractive condensation, the occluded gases will be driven out and burnt, the flame giving rise to the original light emitted by the nucleus. Now the spectrum of most comets shows only the principal bands of a Bunsen burner, and is therefore adequately explained by the flame of gas containing hydrocarbons such as have been found in meteorites; but Dr. Huggins has observed in the spectrum of more than one comet, not only hydrocarbon, but cyanogen bands; and, although carbon and nitrogen combine readily in the electric arc, a coal-gas flame in air shows no trace of the spectrum of cyanogen, and it would certainly put some strain on our credulity if it were asserted that cyanogen was one of the gases brought ready-formed by meteorites from stellar space. Dewar and I have, however, recently shown that if nitrogen already in combination, as, for instance, ammonia, be brought into a hydrocarbon flame, cyanogen is produced in sufficient amount to give in a photograph (though not so as to be directly visible) the characteristic spectrum of cyanogen as it appears in the comet. It is therefore no longer necessary to make any other supposition to account for the cyanogen bands in the spectra of comets, than that ammonia, or some such compound of nitrogen, is present as well as hydrocarbons in a state of ignition.

Quite recently Dr. Huggins has observed that the principal comet of this year has a spectrum of an entirely different character, but he is not yet able to say to what elements or compounds it is probably due. The notion that comets may bring us news of distant parts of stellar space, towards which our system is driving, where the atmosphere is not like ours—oxygen and nitrogen—but hydrogen and hydrocarbons, may fascinate the fancy, but the laws of occlusion oblige us to think that the meteorites have not merely wandered through an attenuated atmosphere of hydrogen and hydrocarbons, but have cooled in a much denser atmosphere of those substances, which we can only conceive as concentrated by the presence of a star or some large aggregation of matter. They may, perchance, have come from some nebulous mass, for Draper and Huggins tell us that in the great nebula in Orion hydrogen is dense enough and hot enough to show some of its characteristic lines, besides the F line which is seen in other nebulæ, and is the last to disappear by reduction of density. No comet on visiting our system a second time can repeat

the exclusion of its occluded gases unless its store has been replenished in the interval. Tacchini has recently observed that Encke's comet, which is one of short period that does not travel beyond the limits of our system, shows the usual spectrum of three bands. If this observation should be confirmed it will be very difficult to account for the replenishment of its occluded gases. But Encke's comet is a very small object, and one cannot feel very certain about its spectrum, and it will be interesting to see, when Halley's comet next returns, whether it shines only by reflected light or gives us, like so many others, the banded spectrum of hydrocarbons.

The following Papers were read:—

1. *On the Legal Flashing Test for Petroleum.* *By* F. A. Abel, *C.B.*, *F.R.S.*, *F.C.S.*

The author commenced by pointing out defects in the old legal flashing test, called the open test, and in the test used in America, called the fire test, and the circumstances that led to his investigation of the subject, resulting in the perfection of a close flashing test, which in 1879 became the legal flashing test by Act of Parliament, and which since that time has been used in the United Kingdom with satisfactory results. After a time this test had been adopted in the United States and by the German Government. In course of the investigations instituted in Germany Dr. Foerster and others had noticed (what had also become apparent in this country) that decided variations in atmospheric pressure introduced considerable variations in the test, when applied to one and the same sample of oil, either at different localities or during a continuance of very different atmospheric conditions. This had led the German Government to adopt a system of corrections for atmospheric pressure in applying the test to the examination of petroleum samples. The subject had been examined into by the author and Mr. B. Redwood, and a series of observations, instituted by the latter in different parts of Switzerland, differing considerably in altitude, had indicated that very constant differences in the flashing point of a particular oil were occasioned by variations of pressure, the difference appearing to amount to about two degrees Fahr. per inch of mercury. The subject was still under investigation, with a view to the adoption of a proper system of correction in practice. Another point was the effect of considerable variations in atmospheric temperature upon the flashing point of an oil. Messrs. Abel and Redwood had carried on a series of experiments for the purpose of ascertaining to what extent variations in the temperature of a sample, and in the temperature of the locality where it was examined, would affect the flashing point under the Abel test, and it had been established that it was not merely necessary to cool down the sample of oil immediately before testing it, when the temperature of the atmosphere exceeded 65° Fahr., according to the directions given in the Act, but that it was also imperative to maintain the oil to be tested for some considerable period at a low temperature, if it had been stored for any length of time in a locality where the temperature exceeded that above specified.

The Indian Government had recently adopted, in a Petroleum Act, without any modification, the instructions relating to the use of the flashing test included in the English Act, and the serious difficulties to which this had given rise in connection with large importations of petroleum into India from the United States, where they had passed the prescribed test, while on arrival at Bombay they exhibited considerably lower flashing points, had led the author to examine into the subject in conjunction with Mr. Redwood, who has lately proceeded to India with the view of thoroughly examining into the conditions to be fulfilled for securing the attainment of trustworthy results by the application of the flashing test in a tropical climate.

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2. *The Influence of Aqueous Vapour on the Explosion of Carbonic Oxide and Oxygen.*[1] *By* H. B. Dixon, *M.A.*

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[1] Printed in *Chemical News*, vol. xcvi. p. 151.

3. *The Velocity of Explosion of a Mixture of Carbonic Oxide and Oxygen with varying quantities of Aqueous Vapour.*[1] *By* H. B. Dixon, *M.A.*

The author endeavoured to compare the velocities of explosion of mixtures of carbonic oxide and oxygen with varying quantities of aqueous vapour by observing the pressure registered in a mercurial gauge attached to the Eudiometer in which the gases were fired. In each experiment the same mass of carbonic oxide and oxygen was exploded at nearly constant temperature and volume. The gauge was U-shaped and contained air in the closed limb. An index, similar to those used in Six's thermometers, was carried up and left at the highest position reached by the mercury. Near the bend of the gauge, two bulbs were blown in the tube as reservoirs, enabling the mercury to be lowered in the Eudiometer without permitting the air to escape from the closed limb.

In two experiments a trace only of aqueous vapour was present. The Eudiometer was dried at 80° C by drawing through it for half an hour air which had passed through two sulphuric acid drying tubes and a small tube containing phosphoric oxide. It was found that, by this method of drying, just sufficient aqueous vapour remained in the tube to enable the explosion to take place slowly when sparks from a Ruhmkorff's coil were passed through the mixture of carbonic oxide and oxygen. In the first experiment several sparks were passed before the gases took fire. In both experiments the flame took about two seconds in passing down the length of 500 mm. occupied by the gases in the Eudiometer. In three other experiments measured quantities of aqueous vapour were added, the vapour being kept below the saturation point; and in the last two experiments the space was saturated with aqueous vapour, and the sides of the Eudiometer were wet. The following table gives the quantities of aqueous vapour in each experiment, the readings of the pressure gauge and the pressures corresponding with these readings.

Explosion of Carbonic Oxide and Oxygen with varying quantities of Aqueous Vapour.

	Tension of CO + O	Tension of aqueous vapour.	Reading of gauge before explosion.	Pressure in gauge before explosion.	Reading of index after explosion.	Pressure registered by gauge.	Temperature of gases.	Length of column of gases exploded.
	mm.	mm.		mm.		mm.	C.	mm.
1	200	trace	229	533	236	562	33°	500
2	200	"	"	"	236·2	563	33°·2	500
3	200	8·7	"	"	249·2	620	33°	505
4	200	9·4	"	"	249·6	622	33°·5	505
5	200	25	"	"	249·4	621	34°	514
6	200	38 (saturated)	"	"	252·6	638	33°·3	524
7	200	40 (saturated)	"	"	252·6	638	34°	525

4. *On the Boiling Points and Vapour Tension of Mercury, of Sulphur, and of some Compounds of Carbon, determined by means of the Hydrogen Thermometer.* *By* Professor J. M. Crafts.—See Reports, p. 317.

5. *On the Occurrence of Tellurium and Selenium in Japan.* *By* Professor Edward Divers, *M.D.*, *and* Masachika Shimosé.

Notice of the occurrence of tellurium and selenium in sulphuric acid made from Japanese sulphur was given by one of the authors to the British Association at its

[1] Printed in extenso, *Chemical News*, vol. xcvi. p. 151.

last meeting. They can now give some particulars which they have since learned concerning the nature of this occurrence.

They obtained large quantities of the deposit from the chambers of the Government sulphuric acid works at Osaka, and found therein both selenium and tellurium; but all the specimens they could get of the sulphur burnt at these works failed to yield these substances. Apparently the stock there of telluriferous sulphur had been all consumed, and as these works have now ceased to be used, no new supplies of sulphur come to them. There are, however, private works at Osaka—the Kawaguchi Sulphuric Acid Works—and from these they have got a sulphur, a specimen of which will be exhibited to the meeting. This sulphur is quite different from ordinary sulphur in colour, being reddish-yellow. It has long been distinguished by the Japanese from ordinary sulphur under the name of *seki, riu seki*, massive red sulphur. The sulphur, of which a specimen is exhibited, is stated to come from Iwōshima (sulphur island) off the south of Japan. A specimen of sulphur not so red in colour in the mineralogical museum of this College, and labelled 'From Iwōshima,' also contains selenium and tellurium. Another specimen in this collection of minerals, closely resembling that exhibited, and containing these rare substances, is labelled as coming from the province of Echiu (Ishikawa prefecture) in the west of Japan.

The specimen exhibited is not the sulphur in its native form, but in a refined state obtained by liquation, and the same appears to be the case of the specimens in the College museum. It will be seen to be a mixture of yellow and red sulphur. The yellow they have found to contain only traces of tellurium and selenium.

The red sulphur has been analysed with the following results. For this analysis they are indebted to Mr. Tetsukichi Shimidzu, a student of chemistry in their College, who kindly consented to work with them lately, as they were pressed for time in consequence of the specimen of red sulphur having been only lately obtained.

Composition of Telluriferous Sulphur.

	Per-centage.
Tellurium	0·17
Selenium	0·06
Arsenic	0·01
Non-identified substance	—
Earthy non-volatile matters, only a trace	
Sulphur, by difference, nearly	99·76
	100·00

The occurrence of tellurium along with sulphur, belonging as these elements do to the same chemical group, is, the authors think, of particular interest, as hitherto tellurium has been only found in the pure state, or more commonly, like sulphur, in combination with metals.

They have done much work upon the deposit from the vitriol chambers, and the tellurium and selenium they have separated from it, but they wish now only to lay an account of the composition of this deposit before the meeting, thereby to complete the natural history of the subject, as they hope to publish on a future occasion the results of their other work.

The mud-like deposit settled down on standing, leaving a pale yellow acid, supernatant liquid, which was principally dilute sulphuric acid, and which had a specific gravity of 1·15. Its colour was due to ferric sulphate, present in not inconsiderable quantity. The authors obtained from one litre of this liquid

Tellurium, 0·37 grams.
Selenium, 0·15 „

They abstain from giving analytical details at present.

The deposit was drained of its liquor as far as practicable upon a filter, was purposely not washed, and was air-dried in the sun. Its analysis gave the following results:—

		Per-centage.
Selenium		10·5
Tellurium		1·2
Sulphur, elemental		6·5
Earthy insoluble matters		24·4
Lead sulphate		29·5
Sulphuric acid Water Organic matters Arsenic Iron, a very little A non-identified substance	by diff.	27·9
		100·0

The point which will attract attention in this analysis is that, whereas the quantity of tellurium is to that of the selenium as 5 to 2 in the sulphur, and as 5·5 to 2 in the liquid with the deposit, it is only as 1 to 9 in the solid part of the deposit. The explanation of this discrepancy is simple. They find by experiments with the deposit itself and by others with pure tellurium, that tellurium in the finely divided state readily oxidises in water exposed to air, and much more rapidly in the presence of acid than not, whereas selenium is not sensibly affected. Therefore the deposit, exposed as it had been to the air, contained much selenium with but little tellurium, most of the tellurium having oxidised and gone into solution in the liquid. It was to avoid further dissolution of the tellurium that they did not wash the deposit for analysis.

The deposit is of a grey-red colour, with a few bright yellow points, probably orpiment, as yellow selenium sulphide is not permanent. On distilling the air-dried deposit in clay retorts they found that the tellurium as well as the selenium all distilled over. Much water and sulphur dioxide were given off, and at first also a bright yellow sublimate, believed to be orpiment. The contents of the retort, where the temperature had not been too high, contained galena, formed during the heating, possessing a strong metallic lustre and marked crystalline form.

FRIDAY, AUGUST 25.

The following Reports and Papers were read:—

1. *Report of the Committee appointed to investigate by means of Photography the Ultra-Violet Spark Spectra emitted by Metallic Elements, and their combinations under varying conditions.*—See Reports, p. 143.

2. *Report of the Committee appointed to prepare a new series of Tables of Wave Lengths of the Spectra of the Elements.*—See Reports, p. 144.

3. *On the application of the Diamond to Mineralogical and Chemical Analysis. By* Professor VON BAUMHAUER.

The author referred to his earlier memoirs on carbon in its three states, viz.: (1) the octahedral transparent diamond; (2) the apparently amorphous black diamond or *carbon*; and (3) the globular diamond or *bort*, in which he had demonstrated the second to be an agglomerate of small crystals cemented together probably by hydrous oxide of iron, thus standing in much the same relation to the first as does sandstone to quartz, while the bort shows confused crystallisation and so is related to the first as calcedony to quartz. He referred also to the application of carbon to economic purposes, such as drilling rocks, and to

experiments which he had made, conjointly with Professor Behrens of Delft, on its application to chemical and mineralogical researches. He exhibited carbon bores contained in iron handles, the mineral being fixed by an equal mixture of wax and colophonium. These handles are fixed in a turning machine, and thus the hardest minerals can be operated upon as easily as iron by steel. For purposes of chemical analysis this process of obtaining a powder is better than the use of mortars of agate, porcelain, or steel, as the powder has no admixture of particles worn away from the mortar. One great difficulty, however, is that of giving any desired shape to the carbon, owing to its extreme hardness. This difficulty the author had overcome as follows:—A piece of carbon is wholly covered by a thin layer of pipeclay like that used in making tobacco-pipes; after this has dried the part covering the portion of carbon to be removed is taken off. The whole is then heated till the carbon is white hot by the action of a Bunsen flame under a blowpipe, then a stream of oxygen is directed on the carbon through a thin platinum tube until the desired portion is removed by combustion. The carbon is then plunged in oil. Specimens which had been thus acted upon were exhibited.

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4. *On the Action of the Component Salts as Nuclei on Supersaturated Solutions of certain Compound Salts.* By JOHN M. THOMSON, *F.C.S.*

In a paper published in the Chemical Society's Journal, May, 1879, on 'The Action of Isomorphous Salts, in producing the Crystallisation of Supersaturated Saline Solutions,' the author pointed out that if a mixture of dimorphous salts be taken, a separation of the salts may be effected within certain limits by touching the solution with a crystal of one or other of the salts; this separation being limited by and depending on the relative solubilities of the different salts contained in the solution.

The subject of the present paper is a continuation of these observations, employing in this case supersaturated solutions of double salts, where it was possible to obtain such, and acting on them with nuclei consisting of one or other of the component salts in order to find whether any disruption of the compound takes place by the action of the nucleus. The method of carrying out the experiments was exactly the same as that employed before, and fully described in his first paper, the nucleus being added to the solution to be experimented on by one of two methods: (1) by the nucleus being obtained by crystallisation from a supersaturated solution, and in this condition retained in the syphon-tube in the neck of the flask till required for use; or (2) the nucleus being added directly from its mother-liquor in a bulb-tube suspended in a similar manner in the neck of the flask.

In all these experiments, as before, the substances were purified with the greatest care, and the admission of particles from the external air most carefully guarded against.

The following tables give the results obtained with the different groups of salts employed.

Experiments with Double Chlorides, Bromides, Iodides, &c.

Substance in Solution	Nucleus added	Result
$HgCl_2 2(NH_4Cl).3H_2O$ . .	$HgCl_2$ (prismatic) . .	Active
" . .	$HgCl_2$ (deposited from hot solution)	Both active and inactive
" . .	NH_4Cl	Inactive
$HgBr_2 2(NH_4Br).3H_2O$ . .	$HgBr_2$	Active
" . .	$HgBr_2$ (deposited from hot solution)	Both active and inactive
" . .	$(NH_4)Br$	Inactive

Substance in Solution	Nucleus added	Result
$HgI_2(KI)_2$	HgI_2	Active
"	KI	Inactive
$HgCl_2 2(NH_4Cl).3H_2O$ . .	$HgBr_2 2(NH_4Br).3H_2O$.	Active
$HgBr_2 2(NH_4Br).3H_2O$ . .	$HgCl_2$ (prismatic) . .	Active
" . .	NH_4Cl	Inactive
$HgCy_2.NH_4Cl$	$HgCy_2$	Active
"	NH_4Cl	"
Experiments with Double Sulphates.		
$AlK(SO_4)_2.12H_2O$ . . .	$Al_2 3(SO_4).18H_2O$ . .	Inactive
" . . .	K_2SO_4	Inactive
$Zn_3Cu(SO_4)_4H_2O$	$ZnSO_4.7H_2O$	Active
"	$CuSO_4.5H_2O$	Active
Experiments with Double Phosphates and Arseniates.		
$NaNH_4HPO_4,4H_2O$ . . .	$Na_2HPO_4.12H_2O$ . .	Inactive
" . . .	$(NH_4)_2HPO_4$	"
" . . .	$(NH_4)H_2PO_4$	"
" . . .	$Na_4P_2O_7$	"
$NaNH_4HAsO_4.4H_2O$ . .	$Na_2HAsO_4 12H_2O$ . .	"
" . . .	$(NH_4)_2HAsO_4.Aq_2$ . .	"
Experiments with Certain Organic Salts.		
$KNaH_4C_4O_6 4Aq$	$K_2H_4C_4O_6$	Inactive
"	$Na_2H_4C_4O_6$	Active
$K_3Na_3 2(H_5C_6O_7)$	$K_3H_5C_6O_7$	Active
"	$Na_3H_5C_6O_7$	"
$MgNaH_5C_6O_7$	$MgH(H_5C_6O_7)$ . . .	Inactive
"	$Na_3H_5C_6O_7$	"

From these tables it will be seen that, in the case of the double chlorides, bromides, and iodides, the salt of the heavy metal invariably caused the crystallisation of the double salt, whereas the constituent containing the alkali-metal had no action. It was, however, impossible to determine whether the salt causing crystallisation did so by first inducing the deposition of the salt analogous to itself in the solution; experiments are being carried out to endeavour if possible to determine the primary action which takes place. It is, however, a somewhat difficult one to examine.

It may also be observed that when the mercuric chloride or bromide existed in the nucleus in its true prismatic form, crystallisation at once took place, but that when its deposition from its solution took place at a higher temperature the results were various. On examining this point he finds that the crystalline form of the mercuric chloride and bromide change when so deposited, which may readily account for the alternation in those cases. The crystalline form also of the double salt is more nearly allied to the form of the heavy metallic salt than to the constituent containing the alkali-metal. In the case of the double cyanide and chloride, however, there is a distinct difference from the halogen salts employed in the first-mentioned experiments, both components producing the crystallisation of the double salt.

It seems probable, therefore, that the double salts formed from these monobasic acids, although they form good supersaturated solutions, are not so firmly united together as to withstand the disturbing influence of certain of their constituents; but that the disruption produced by them is not sufficient to cause the decomposition of the body, and consequently the double salt is deposited. In the case last mentioned, also, of the double cyanide and chloride, both salts are deposited as the final result of the crystallisation.

In experimenting with mercuric iodide, this substance was introduced by means of a pipette-shaped tube, and the iodide strongly steamed by boiling the flask before it was allowed to cool.

In the case of the alum and double phosphate, however, which may be taken as examples of very definite double salts, neither of the components have any action on the solution. In connection with the alum experiments some interesting results were obtained from the double sulphate of zinc and copper, known as 'Lefort's salt,' the composition of which, according to that author, is $Zn_3Cu(SO_4)_4$, H_2O, and which can be crystallised without decomposition.

Quantities of this salt were dissolved in half their weight of water, zinc sulphate ($ZnSO_4,7H_2O$) and copper sulphate ($CuSO_4,5H_2O$) being employed as the nuclei.

In these cases both the constituents were active in causing crystallisation, that from the zinc sulphate nucleus being more rapid than that from the copper sulphate nucleus. An examination of the crystals deposited showed that they were crystals of the double salt, and their deposition presented some very peculiar phenomena, referred to at length in the paper.

In the last group of salts employed, viz., the tartrates and citrates, it will be observed that in the case of two of them one of the constituents was active and one remained inert. It now became important to examine, if possible, the composition of the crystals which were gradually deposited from the nucleus. For this purpose experiments were carefully performed in flasks containing the Rochelle salt, to which the nuclei of neutral sodium tartrate were added by means of the syphon-tubes. The crystals gradually and slowly formed from the point of the syphon-tube, and were allowed to grow till a considerable cluster had formed, and a great part of the salt had been thus removed from the solution in the flask. The deposit adhering to the syphon-tube was withdrawn from the mother-liquor removed from the flask, washed with ice-cold water, pressed between blotting paper, air-dried, and analysed. On analysis the deposit gave numbers closely agreeing with the composition of Rochelle salt.

Now it is to be observed that the crystals forming the deposit here in no wise resemble those of Rochelle salt, but closely resemble those of sodium tartrate, giving us evidence of the probable dimorphism of Rochelle salt.

At present it is difficult to see why the sodium tartrate should be active and the potassium salt inactive; but it may be remarked that the solubility of the sodium salt is less than that of the potassium salt, which may perhaps account for its activity. A corresponding result has been observed with the citrate of potassium and sodium, in which the sodium citrate has always proved active, whilst the potassium salt is inactive. Here also the solubility of the potassium salt is greater than that of the corresponding sodium salt.

In the case, however, of the double magnesium and sodium citrates, the results were different, both of the constituent salts proving inactive to the double salt.

From these experiments it will be seen that the double salts of monobasic acid apparently suffer disruption more easily than the salts from acid of higher basicity, like sulphuric and phosphoric acids, but that in the case of the first of these two latter acids, salts may exist, like Lefort's salt, which is acted upon by the constituents.

It will be observed, however, that such salts indicate more of molecular than of atomic grouping in their constitution, whereas in the alum and double phosphate we have a firmer union of the salts. This is also, the author thinks, to be observed in the salts from the organic acids; by its mode of formation and its

composition, the double sodium and potassium citrate appears more like a molecular grouping of the constituent salts, and both constituents are capable of causing disruption, whereas in Rochelle salt and the magnesio-sodic citrate, there is evidence of a closer binding of the component salts. In the case of Rochelle salt only one constituent produces disruption, and in the case of the magnesio-sodic citrate, neither constituent has any action. It is to be hoped that experiments carried out on these solutions may assist in the examination of the condition of such salts when in a state of solution.

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5. *On the Decomposition by Heat of Chlorate of Potassium. By* ALBERT RILLIET *and* Professor J. M. CRAFTS.

The cause and circumstances which favour this decomposition have been the subject of much study, and the elder Mitscherlich and other great authorities have offered solutions of the question, but none has met with general acceptation. The authors desire to present a few new facts without dwelling further upon any theory than is necessary to bring out certain analogies, which have guided their experiments, and which they hoped might lead to a partial explanation of some points connected with the phenomenon.

They have enlarged the knowledge of the number of bodies favouring the disengagement of oxygen, and the discovery that pure metallic silver, reduced by hydrogen from the chloride at a high temperature, has this action, appears to destroy the usual theories regarding the function of the metallic oxides, which produce the same effect.

There is no necessity for recognising here any difference between the affinity which comes into play during an act of solution, and that which governs any chemical combination, and they supposed that the so-called catalytic bodies might have the property in common of absorbing oxygen. Black oxide of manganese was exposed to oxygen at exactly the conditions of the experiment in which it had promoted the decomposition of chlorate of potash, but no action could be discovered which would explain the possibility that it might have a strong attraction for an oxygenised body presented to it.

A curious case was noticed, in which chemical affinity might be supposed to determine the reaction. Gas-retort carbon can be completely burnt, chiefly to carbonic acid, by contact at about 340 degrees with pulverised chlorate of potash. There is no fusion; every trace of the carbon gradually disappears, and the greyish powder becomes white. The operation lasts one or two days. An admixture of more than 10 per cent. of carbon provokes a violent reaction, with disengagement of heat.

In the same way that chemical formulas are used to express certain characteristic qualities of bodies, symbolized under a conventional image of their constitution, it is allowable to present possibilities of molecular action by a picture, which bears little or no relation to the probable physical conformation of matter.

Suppose all the atoms of a compound to be equidistant, and the distances to be equally increased by an accession of heat, the sphere of chemical attraction might, after passing a certain point, be overcome, and the only limit to a decomposition with explosive rapidity would be the absorption of heat during the process. If the condition of the molecule is more truly to be symbolised by atoms at irregular distances irregularly affected by heat, which would cause from time to time a single atom to overlap the boundary, a slow decomposition by heat is understandable. One can also imagine heat from different sources, or conveyed through different media, although producing this same mean movement of the particles, still affecting them differently, in one case causing a large increase of movement in a small number of atoms, in another producing the equivalent temperature by a smaller movement imparted to a larger number of atoms. This last conception may perhaps explain the intervention of certain bodies in the decomposition, and it may be that their contact imparts heat-impulses of different qualities from those of the substances, like silica and chloride of silver, which have no decomposing

action. The authors have devised no experiments suited to test this hypothesis in a satisfactory manner, but the following account of the mode of decomposition of chlorate of potash at a constant temperature is not inconsistent with its adoption.

The temperature was maintained at a fixed point to within $0^{\circ}\cdot 2$ by means of mercury boiling under a constant pressure.

Pure chlorate of potash begins to give off oxygen at 330° to 340°, far below its melting point, and the decomposition goes on for several weeks before it becomes imperceptibly small. After the limit is reached, if the temperature is raised, a fresh decomposition tending towards a new limit takes place. At the temperatures chiefly used, only a small percentage of the salt undergoes decomposition.

The first stage of the decomposition is marked by a lower melting point of the mixture of the residual salts, which usually fuse after several days.

Pure chlorate of potash must undergo decomposition before fusion, although the change of weight may be slight in a rapidly conducted operation.

The addition of 10 to 20 per cent. of any of the substances known to favour the decomposition has an effect exactly similar to the raising of the temperature: the limit of decomposition is reached as before after a certain time.

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6. *Hydrocarbons of the Formula* $(C_5H_8)_n$.[1] By Professor W. A. TILDEN, *F.R.S.*

To existing knowledge of isoprene the author adds the facts that its tetrabromide $C_5H_8Br_4$ is a liquid which refuses to solidify at $-18°$, and which cannot be distilled without decomposition. The oxidation of isoprene by nitric acid leads to the formation of a considerable quantity of oxalic acid, whilst chromic acid produces formic and acetic acids. The remarkable production of caoutchouc by the action of certain chemical agents upon isoprene led the author to make some experiments with a view to ascertain whether this hydrocarbon could be obtained from other sources, and bearing in mind the polymerisation of isoprene into a true turpentine by the action of heat, it seemed not improbable that turpentine oil might be made to yield it. On passing turpentine vapour through a red-hot tube, a complex mixture of hydrocarbons is obtained, from which may be isolated about 2 per cent. of a volatile liquid, having the composition of isoprene and, so far as at present observed, all its properties. The paper includes a theoretical discussion of the formulæ assignable to the eight possible compounds having the composition C_5H_8, and of their relation to the terpenes.

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7. *On the Activity of Oxygen, and the Mode of Formation of Hydrogen Dioxide.*[2] *By* C. T. KINGZETT, *F.I.C., F.C.S.*

In this paper the author discusses the mode of formation of ozone and peroxide of hydrogen by processes of slow oxidation. Referring to the views of Thénard, Lamont, and others, and considering, in connection therewith, the results obtained in his investigations of the atmospheric oxidation of phosphorus and the terpenes, he discards the notion that in such processes molecular oxygen is split up into free atoms by any outside act, so to speak. Turpentine and other terpenes absorb the whole molecules of oxygen and ozone, and in both cases yield an identical organic peroxide, which, by mere contact with water, produces hydrogen dioxide as a secondary product. This secondary change is the result of a simple transference of oxygen, or re-distribution of molecules.

The author further criticises the views of Traube ('Ber.' 15, 659–675), and adduces evidence against the idea that in the formation of hydrogen dioxide it is water that is decomposed. Finally, he proposes a new representation of the constitution of hydrogen dioxide. Believing that oxygen has a variable acidity, and may behave as a triad or tetrad, he represents peroxide of hydrogen as oxygenated water, OOH_2 rather than hydrogen dioxide, HOOH; this new representation more adequately explaining the changes that the substance is known to undergo.

[1] Published *in extenso* in the *Chemical News*, vol. xlvi. p. 120.

[2] See *Chemical News*, vol. xlvi. p. 141.

8. *Metallic Compounds containing Bivalent Hydrocarbon Radicals. Part III.* *By* Professor SAKURAI, *F.C.S.*

By acting on monomercuric methylene iodide, $HgCH_2I_2$—the preparation of which is described in the Report, 1880, p. 504—with mercuric chloride, a compound is obtained which is shown to be monomercuric methylene chloriodide, $Hg(CH_2)''ClI$. This compound is soluble in ether, chloroform, and alcohol, and crystallises in thin shining white plates, m.-p. 129°. The action of iodine on this compound shows it to be constituted thus: $ClCH_2HgI$, inasmuch as it is thereby converted into mercuric iodide and methylene chloriodide, thus: $\begin{array}{r|l} ClCH_2 & HgI \\ I & I \end{array}$

Methylene chloriodide, CH_2ClI, is a liquid boiling at 109°, and having a specific gravity of 2·49 at 20° C. The boiling point of this compound is the mean of the boiling points of methylene chloride and methylene iodide.

SATURDAY, AUGUST 26.

The Section did not meet.

MONDAY, AUGUST 28.

The following Reports and Papers were read:—

1. *Report of the Committee on the Calibration of Mercurial Thermometers.* See Reports, p. 145.

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2. *Third Report of the Committee upon the present state of our Knowledge of Spectrum Analysis.*—See Reports, p. 120.

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3. *On the Reversals of the Spectral Lines of Metals. By* Professor LIVEING, *F.R.S., and* Professor DEWAR, *F.R.S.*

The authors have made a regular study of this subject, not only with a view to trace the parallel between the conditions of the elements as they exist in the sun and those in which they can be placed on earth, but also because a knowledge of the reversible lines may help to distinguish those due directly to the vibrations of the molecules from those produced by superposition of waves or by some strain upon the molecules, such as an electric discharge might give. They classify the reversals as follows. I. Reversals where the expanded line itself gives the background against which the absorption line, narrowed because density of the absorbent is less than that of the emittent vapour, is seen. These are the reversals most generally known. II. Reversals in which there is little or no expansion of the lines, and the background is either the hot walls and end of a tube, the hot pole of the arc, or such part of the arc as is so full of lines as to be nearly continuous. Many such reversals, including many lines of iron and other metals, were exhibited in photographs. III. Reversals in which the background for the absorption was produced by the expansion of a line of some other metal. Photographs of the reversal of iron and other lines seen against the expanded magnesium lines were exhibited. IV. Reversals by the introduction into the crucible in which the arc was passing, of a very gentle current of hydrogen, coal-gas, or ammonia, by which the metallic lines are almost all swept away, and the continuous spectrum much increased. V. When a carbon tube, passed through a perforation in a block of

lime, is made the positive electrode of the arc, while a carbon rod, passed into another perforation in the lime so as to meet the tube in the middle of the block, is made the negative electrode, the tube becomes gradually heated up, and in the direct line of the tube the metallic lines are seen bright because there is no background, but against the hot walls of the tube the same lines are seen reversed. The effects of gradually increasing temperature were traced as the tube was gradually heated. VI. Occasionally a double reversal of lines occurs, and a photograph was exhibited showing an expansion of the magnesium lines, between K and L, which extended so far as to produce reversal of the most refrangible two of the cyanogen bands, the magnesium producing also a broad absorption band, against which the magnesium triplet was seen bright and sharp. This seems due to the less dense, but intensely heated, magnesium vapours, pushed forward up the tube by the sudden burst of dense vapour evolved on dropping a fresh piece of magnesium into the arc.

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4. *On the Electric Furnace.*

By Dr. C. W. SIEMENS, *F.R.S.*, *and* Professor A. K. HUNTINGTON.

The electric furnace has previously been described in the Journal of the Society of Telegraph Engineers, June, 1880. It has since been found advisable to surround the furnace with a coil. By this means the direction of the arc can be regulated at will, and the tendency which it has to fly to the sides of the crucible be checked.

The electrodes may be of such carbon as is used in electric lighting or of any other convenient conducting substance. They may, if desired, be cooled by circulating water through or round them, or by exposing them as far as possible to the air. For example, in one experiment a ½in. nickel positive pole was employed, the lower end being inserted into a solid rod of copper about 1 in. square by 6 in. long. With this pole, no other means of keeping it cool being adopted, 1 lb. of grain nickel was fused in a clay crucible and poured in eight minutes, starting with all cold. The electrode was but little attacked, and no leakage occurred.

There are two great advantages possessed by the electric furnace, viz., that the temperature attainable is practically only limited by the refractoriness of the materials of which the furnace is constructed, and that the heat is developed immediately in the material to be fused, instead of first having to pass through the containing vessel. The temperature to be obtained by the use of fuel is limited by dissociation. Deville has shown that carbonic acid undergoes dissociation at the ordinary atmospheric pressure at about 2,600° Cent. = 4,700° Fahr.

In the experiments made by the authors, five D-2 machines driven by a Marshall's 12-horse power engine were employed: one being used as an exciter. The current ranged between 250 and 300 ampères. The most refractory clay crucibles supplied by the Patent Plumbago Crucible Company were invariably cut through in a few minutes, and, except for experiments of short duration, were useless. Plumbago crucibles stood exceedingly well. Obviously, however, they could not be employed for all purposes, owing to their tendency to cause carburisation of the metal experimented with. In some experiments the fusion of metal was effected in a bed of lime, sand, or electric light carbon-dust. The latter is a very bad conductor, and, as in the case of lime and sand, allows the arc when once formed to maintain a passage through it to the metal beneath.

Wrought Iron.—Six pounds of wrought iron were kept under the action of the arc for twenty minutes, and the metal then poured into a mould. It was found to be crystalline, and could not be forged. This is the result which has always been obtained when iron, nickel, or cobalt have been fused. Although the remedy, viz., the addition of a little manganese just before pouring, is well known, the cause remains still unexplained.

Steel.—As much as 20 lbs. of steel files have been melted in one charge, the time required being about one hour, starting with the furnace hot. With such large quantities the metal has invariably been full of blowholes.

White iron, fused in a clay crucible for thirty minutes, when fractured did not appear to have undergone any change. White iron and coke were introduced into the furnace; the resultant metal was slightly greyer than the original. When, however, retort-carbon was substituted for the coke a good grey iron, soft and easily workable, was readily obtained in fifteen minutes, starting with the crucible hot. On another occasion, starting all cold, at the end of thirty minutes the metal, although it had been well fused, had not been rendered greyer. The difference between these two results was possibly due to the temperature being somewhat higher in the one case than in the other. This is a point of considerable practical interest. Four pounds of white iron, fused with carbon-dust for three-quarters of an hour, yielded a very grey crystalline iron. In another experiment, in which 8 ounces of grey iron, produced in the electric furnace from white iron, were re-melted in carbon-dust for ten minutes, a very grey metal was obtained, from which on slow cooling a large quantity of graphite separated.

Cast iron, fused and kept under the action of the arc for forty-five minutes in carbon-dust, was not materially changed as to greyness, and the general character of the metal as to the way in which it worked under the tool was not materially altered. The object of the experiment was to ascertain the maximum amount of carbon iron is capable of taking up under circumstances presumably the most favourable. The result is hardly that which would have been anticipated. Some of the same cast iron was fused for fifteen minutes under lime, which nearly covered it. The character of the fracture of the metal was but little altered by this treatment, when slight differences, due to the rate of cooling, are taken into account. A strong smell of phosphoretted hydrogen or of a phosphide was perceived—probably the latter. This was only observed in the experiment in which lime was used. The lime employed still retains a very offensive odour.

When *spiegeleisen* was fused in a plumbago or a clay crucible graphite separated as the metal cooled.

Siliceous pig iron containing about 10 per cent. silicon was fused by itself; it showed but little change, except that some graphite separated. A similar result was obtained when 5 lbs. of the siliceous pig were fused for one hour in carbon-dust. On fracturing the ingot obtained, a large quantity of scales of graphite was found in a hollow which traversed nearly the whole length of the ingot at its centre. The fracture of the metal was still that so characteristic of highly siliceous iron, and was practically the same as that of the original pig iron.

A series of experiments was made to determine the maximum amount of carbon pig iron is capable of taking up in the presence of a given quantity of silicon. Grey cast iron and pig iron containing 10 per cent. of silicon were fused together in carbon-dust, the ratio between them being varied so as to yield metal with from ¼ per cent. to 9 per cent. of silicon.

A similar series was made, only substituting sulphur for silicon. No odour of sulphurous acid was perceived; therefore, presumably, no sulphur was volatilised. This is somewhat remarkable, considering the nature of the experiment. It was thought that investigations of this kind might have an important practical, as well as more purely scientific, interest—admitting, for the sake of argument, that any such distinction really exists—in assisting to determine the conditions in the blast furnace, &c.

Nickel.—A positive pole of this metal—cast malleable by Wiggin & Co.'s process[1]—½-in. in diameter, was passed through a hole in the bottom of a clay crucible. A carbon negative pole was used, but soon after the commencement of the experiment a deposit of nickel formed on the end of it, so that practically it was a nickel pole. This deposition of metal on the negative pole was also observed with some other metals—notably with tungsten. Whilst disclaiming any special knowledge on the point, Professor Huntington suggested whether this phenomenon—which is the reverse of that generally recognised as taking place—might not depend on the relative volatility of the matter composing the poles. In the furnace arranged as just described, 1 lb. of grain nickel was fused and poured in

[1] See paper on 'Nickel and Cobalt,' by Professor A. K. Huntington, in July number of the *Journal of the Society of Chemical Industry*.

eight minutes. The fused metal had a brilliant granular fracture. It could not be cut properly in the shaping machine, shearing off under the tool. One pound of grain nickel fused in carbon dust for twenty-five minutes yielded a dark grey carburised metal, which worked well under the tool. On another occasion an equal quantity of nickel, similarly treated, gave a 'blowy' metal, which could not be worked. Some carburised nickel, made as described above, was fused in a clay crucible for twelve minutes, and allowed to cool gradually in the furnace; the fracture became whiter, and the grain closer.

Copper.—Three-quarters of a pound of copper were fused for about half an hour in carbon-dust. On examining the result, it was found that all but about ¾-oz. had been vaporised. Those who were present during the experiments suffered no ill effects from the atmosphere charged with copper, which they must have breathed.

Platinum.—Eight pounds of platinum were rendered perfectly liquid in about a quarter of an hour.

Tungsten.—Half a pound of tungsten in powder was subjected to the action of the arc in a clay crucible. Dense fumes were evolved, a cavity about 1½-in. across the top being formed. The furnace was allowed to cool down slowly. When the crucible was removed, it was found to have been very much attacked below the point to which the arc extended. The inference is that the crucible had been attacked by the metal at the temperature of the experiment. The metal was fused only to an inappreciable depth beneath the cavity formed by the arc. The unfused metal underneath was covered with very beautiful iridescent crystals of tungsten, which under the microscope appeared to be well-formed prisms. They have not yet been measured. The crystals had evidently been formed by the slow cooling of the vapour distilled down from the surface.

A very large number of experiments was made with tungsten, the results of which showed that it could not be fused, except in very small quantities at a time. It was possible to build up a small ingot by fusing a little of the tungsten, and then adding little by little gradually. Even then the pieces obtained were for the most part spongy and unsatisfactory. The best results arrived at were when tungsten which had already been fused was employed in the building-up process. When once the metal had been fused, it did not fume much in melting, doubtless owing to the greatly reduced surface exposed.

Tungsten fused in the electric furnace is, when untarnished, pure white, and brittle, the grain being very close. Tungsten hitherto has only been obtained as a grey powder, by reducing the oxide with carbon or hydrogen, or in minute globules in the ordinary small electric arc. Tungsten has its fusing point lowered by the addition to it of carbon. Under these conditions a solid piece of moderate size can, without much difficulty, be obtained. From 1,000 grains of powder fused in carbon-dust 650 grains were recovered, the remainder having been volatilised, and from 450 grains of the fused metal 410 grains were obtained on re-fusion. One piece of tungsten which had been treated under the conditions most likely to cause it to be highly carburised was analysed. It contained 1·8 per cent. of carbon. The metal was very white, close in grain, and brittle.

From the foregoing experiments it is clear that the amount of any given metal which can be successfully fused in the electric furnace, and the time required in effecting the fusion, are dependent on (*a*) the relation between the volatilising point and the fusing point, *i.e.* the extent to which the volatilising point is higher than the fusing point; (*b*) the conductivity of the metal for heat.

It thus happens that platinum can be more readily melted than steel, and in greater quantity for a given expenditure of energy. This inference is believed by Professor Huntington to be justified by the observations and experiments so far made.

It still remains to examine chemically the specimens referred to in this paper.

5. *The Aerorthometer, an Instrument for correcting the Measure of a Gas.*[1] *By* A. VERNON HARCOURT, *M.A., F.R.S.*

In determining the mass of a gas, it is generally more convenient to measure than to weigh. The volume multiplied by the density, which is known, gives the mass, if the volume has been measured under standard conditions. Otherwise, the actual measurement must be corrected. The usual formula for correction, $V = \frac{v\,(P-p)}{760(1+a\,t)}$ requires the observation of (1) v the actual volume, (2) P the height of the barometer, (3) t the temperature, (4) p the tension of aqueous vapour at t given by a table.

A reading of the aerorthometer gives at once the quantity $\frac{760\,(1+a\,t)}{P-p}$; and thus, to find V, the normal volume, it is only necessary to divide v by this reading.

The instrument consists of two narrow vertical tubes, the one open above, the other terminating in a a bulb whose capacity, including that of the stem down to the first graduation, is 1,000 of the units into which the stem is divided; both tubes are connected below with a reservoir from which mercury can be driven up the tubes by the pressure of a screw. When the mercury stands at the same level in the open and closed tubes, the air in the closed tube, which at 0°C. and 760 mm. occupies 1,000 volumes, is under the existing atmospheric pressure. It has also the temperature of the surrounding air. It is thus under the same conditions as the gas in any vessel near it. The volume read upon the aerorthometer is to 1,000 as the observed volume of the gas in the measuring vessel is to its normal or corrected volume.

For use in the ordinary case of measuring a gas over or in presence of water the aerorthometer is charged with a minute drop of water. If filled with dry air its reading gives $\frac{760\,(1+a\,t)}{P}$. For technical purposes the graduation '1,000' marks the volume which the inclosed air occupies at 30 inches Bar. and 60° Fahr.

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6. *A Revision of the Atomic Weight of Rubidium.* *By* CHARLES T. HEYCOCK, *B.A.*

The element rubidium has an atomic weight assigned to it usually of 85·4, and consequently is removed from a whole number. Its revision therefore became of interest, to see whether with improved methods it could be brought in accordance with the hypothesis of Prout.

The experiments here detailed are merely preliminary to a large number shortly to be undertaken. The crude rubidium chloride was obtained from Dr. Theodore Schuchardt of Goerlitz; it was separated by Godeffroy's method with the alums. In order to further purify it, the author converted the crude chloride into sulphate, and decomposed this with an equivalent quantity of barium bitartrate. After filtration, the mixed bitartrates of potassium, rubidium, and cæsium were repeatedly crystallised, the crops being separated. The bitartrate of rubidium separates from its concentrated solution with ease, provided it is constantly stirred.

The pure rubidium bitartrate was then decomposed by heating in a crucible of platinum, and the resulting carbonate dissolved out and filtered from the carbon. was divided into two portions, (a) and (β).

(a) was neutralised with excess of pure HCl. evaporated to dryness and fused. The titration was made exactly as detailed by Stas, in his celebrated work, (*Mém. de l'Acad. de Belgique*, tom. xxxv. 1865), *i.e.* by adding to a known weight of silver nitrate an equivalent quantity of rubidium chloride, calculated on the assumption that Rb = 85·0, in other words conforms with the hypothesis of Prout.

The author then found in a beam of yellow light the amount of RbCl in excess

[1] A fuller description of the aerorthometer, with a drawing, will be found *Proc. Roy. Soc.* vol. xxxiv. p. 166.

by means of a solution of $AgNO_3$, containing per gram of solution, 0·0009 grm. Ag. The mean of seven experiments conducted in this way gave him the ratio: Ag : RbCl :: 107·93 : 120·801; this when chlorine = 35·457 gives for the atomic weight of rubidium, 85·344.

The portion β was converted into bromide by means of pure HBr. prepared as described in Mr. Huntington's paper on the atomic weight of cadmium ('Proc. Amer. Acad.') it had a constant boiling point of 126° C. Bar. 777 mm. after fractionating six times.

The first results were all far too high, the RbBr being contaminated with platinum derived from the dish. The last two results when the weights are reduced to a vacuum are not nearly so concordant as might be wished.

RbBr		
4·2365	grms. gave	Ag. : RbBr :: 107·93 : 165·437
12·33595	,, ,,	Ag. : RbBr :: 107·93 : 165·342

whence mean atomic weight as derived from

RbBr when Br = 79·955, 85·389.

These bromide determinations are given with all reserve, as they are influenced to a large extent by the correction for displacement which there is reason to believe is far too high.

The extended experiments will be published shortly. The mean error of the atomic weight deduced from the chloride and bromide by the method of least squares is ± 0·0215. At present rubidium cannot be said to conform to Prout's hypothesis.

7. *On a method of obtaining Ammonia from Shoddy and Allied Substances. By* W. MARRIOTT, *F.C.S.*

The author has for some time been engaged in devising a method of applying on a large scale the principle adopted in any ordinary nitrogenous estimation by means of soda lime, his object being to work up such nitrogenous substances as wool or hair, and convert the nitrogen into ammonia.

Mixing shoddy (the name by which this material is known) with lime and soda, and subjecting the mixture to heat in a retort, has been tried many times and with different apparatuses, but the return in ammonia never paid the cost of working.

Shoddy is a bulky material, so that a retort when charged with it holds but little weight. And if the size and diameter of the retort are increased to overcome this, the shoddy when carbonised is such a bad conductor of heat that the matter in the centre of the retort is but slowly decomposed, although a great expense is incurred for fuel.

To obviate this, and reduce the cost of fuel, he tried the burning of the shoddy in a cupola heated by combustible gases. This, after several failures, he has succeeded in accomplishing, and also in making the process a continuous one.

The principle he applies for this purpose, is to generate the heat of combustion in contact with the nitrogenous matters operated upon, making sure that no free oxygen is left with the products of the combustion.

The construction of the apparatus may be thus explained.

Nos. 1 and 2 are cupolas made of boiler-plate, and lined with fire-brick. In No. 1 cupola, coke and small coal is burnt, the combustion being kept up by means of a fan or air-pump along with high-pressure steam. The gases generated are principally carbonic oxide, hydrogen, and marsh gas, along with the nitrogen of the air blown in. These mixed gases are led into the bottom of cupola No. 2, and there coming into contact with a jet of air, combustion ensues, and great heat is generated, which heat has to pass up through the material in the cupola.

The point to be strictly observed is, that no more air be admitted than is required for the combustion of the gases, and no free oxygen left in the atmosphere heating the organic matters. The ammonia generated, along with the residual gases, are passed through a saturator containing sulphuric acid to absorb

the ammonia, and the gases after passing through a condenser are finally burnt under any appropriate apparatus. This final combustion of the gases does away with any nuisance, besides utilising a considerable amount of heat derived from the combustion of the organic matters.

Different nitrogenous substances require different treatment before being fed into cupola No. 2. Shoddy, for instance, is a dry product, and the nitrogen contained in it is the only substance of value, the ash being worth little.

In preparing shoddy for this purpose, we make a large heap, watering the shoddy with a dilute solution of soda, containing the same weight of carbonate of soda as the shoddy contains nitrogen. The heap of shoddy gradually heats and diffuses the moisture equally throughout the mass. This prevents the dust being carried over by the current into the saturator.

Before charging the prepared shoddy into the cupola it is mixed with about 6 per cent of lime, in a moist powdery state. By this treatment 80 per cent. of the nitrogen is converted into ammonia. The ash-dust and lime fall to the bottom, and are withdrawn as they accumulate. This material is used as a manure.

In applying this principle to nitrogenous matters containing phosphates, such as fish or excreta, no lime or soda is added, and it is thus more of an economical method of drying up these substances than combining their nitrogen into ammonia. But even in drying part, carbonate of ammonia comes over, which is absorbed by the sulphuric acid.

The dried matter, withdrawn as it accumulates, consists principally of phosphates, nitrogenous carbon, and potash. This residue, added to either fish or excreta in an offensive state, completely deodorises it, so that the operation can be carried on without a nuisance. The pressure under which the apparatus is worked must be sufficient to drive the gases and absorbable material through the saturators. A quantity of tar and animal oil gradually comes over and accumulates in the catch-box.

The author has not had much experience in applying this principle to the drying up of excrements such as that obtained by what is called the Rochdale tub system, but he has done sufficient to justify him in saying that it can be economically applied to that purpose.

In his experiments with excreta, instead of using an upright cupola, he used a long horizontal reverberatory furnace, heated on the frame principle, by gases generated in a separate cupola, and burnt so as to leave no free oxygen. The whole of the carbonate of ammonia is expelled at the boiling temperature, and is retained in the saturators.

The residue is a dry carbonaceous powder, containing all the inorganic constituents of the excreta.

Section C.—GEOLOGY.

President of the Section—Robert Etheridge, F.R.S. L. and E., F.G.S.

THURSDAY, AUGUST 24.

The President delivered the following Address:—

For some years it has been the rule or practice that the Presidents should open the sectional meetings with an address, selecting any subject which may seem to them best adapted to the occasion. This custom I believe had its origin in this Section, when the Association met at Aberdeen, and was due to Sir C. Lyell, who was the first to deliver an opening address. He selected for his theme the discoveries of M. Boucher de Perthes, chiefly with relation to the occurrence and association of flint weapons with the bones of extinct animals in the gravels of the valley of the Somme.

The Geological Section, over which during the present meeting I have the honour to preside, embraces a wide field of research, and therefore allows selection from a large range of subjects, so large indeed that it would be difficult to choose an original one that would be acceptable and useful to those members of the Association who may be present. It is thirty-six years since the British Association last met in Southampton, and probably not half-a-dozen members who attended the meeting of 1846 are now present, if living. We are, however, fortunate in having with us to-day one or two who contributed papers to this Section thirty-six years ago.

The Geological Section may be congratulated on its place of meeting this year. Hampshire presents a wide range and field of research to the practical, as well as to the less advanced student in geology. Truly may it be said that this area is classic ground. No less than six distinct formations, with their subdivisions, occur in the immediate neighbourhood and within reach of those members who have honoured the Association with their presence this year. Be it remembered that it is thirty-six years since the British Association met in this city. Since then, or the year 1846, geology has indeed advanced with strides unsurpassed by any other science. The Tertiary rocks of the Hampshire basin alone have received from the hands of private and learned physicists, as well as the long-continued labour of the Geological Survey, the most careful and detailed research. It may well be said that this rich field has not wanted competent labourers, earliest and foremost of whom must be named Webster, Sedgwick, Prestwich, and Edward Forbes, who with Mr. Bristow mapped out with so much care and accuracy the intricate structure of the Isle of Wight. To these must be added, through later research, the names of Searles Wood, Wright, Fisher, Tawney, Keeping, Judd, and others. Other portions of Hampshire and Sussex bearing upon the question of the Anglo-French Tertiary basin, have been elaborately treated by Dixon, Godwin-Austen, Sir C. Lyell, and others.

It may be a fitting preliminary to local communications which will most probably come in, during the course of this meeting, that I should summarise what has been done in this area. This may be familiar to many, but there are others who may wish to examine certain geological localities, the mention of which may induce them to visit spots of much interest. It is scarcely the duty of the president of this Section to devote the time allowed to an opening address to the discussion of any original subject, while work of unusual local interest has transpired during the past year to justify him in drawing attention to a subject of much importance

connected with the stratigraphical position of certain beds in the Eocene strata of the Isle of Wight; a question of local geological interest, as well as bearing upon the correlation of the Tertiary rocks of Hampshire with those of France, Belgium, and Germany. Instead, therefore, of offering to the Geological Section an address on some special subject or branch of general geology, I have deemed it more interesting, and certainly more useful, to lay before you an outline of certain physical features occurring within the immediate neighbourhood, and the district in which we are now assembled.

I purpose therefore to call attention to the local geology of this area, especially as regards the Tertiary deposits of Hampshire and Sussex, as forming or constituting the northern portion of a vast series of deposits once continuous to Northern France, the area now covered by the English Channel and the Solent, and lying in the depression of the jurassic and cretaceous series. The relation also of the Hampshire and Anglo-French basin and its tertiary fauna to that of the London or Anglo-Belgian area will receive notice, as being part of the history of one great period, the strata comprising the two areas being also once continuous, much of it being subsequently removed or denuded away from those areas now occupied by the English Channel and German Ocean.

Before especially noticing the Isle of Wight and the neighbouring coasts, I must state that by laborious search over both old and new ground, and through the very careful examination of collected specimens during the past twenty years, great light has been thrown on the geological structure of many local areas hitherto obscure from want of critical palæontological knowledge being brought to bear upon the fossil fauna or flora characterising the various marine and freshwater deposits with which the surrounding district abounds. Greater precision has of late been arrived at in the chronological arrangement of the cretaceous and tertiary strata which occur both in the Isle of Wight and on the mainland.

Doubtless you are all aware that the strictest investigation as to the distribution and organic contents of the Fluvio-marine Tertiaries of the Isle of Wight, was undertaken by Professor Edward Forbes, when attached to the Geological Survey from the years 1848–56, and subsequently Mr. H. W. Bristow, F.R.S., completed all the older tertiaries and cretaceous rocks of the island, thus producing a complete geological guide to this portion of the Hampshire basin. The structure of the opposite coast to the east, or that embracing Bracklesham Bay, Selsea, and Bognor, was critically treated by Mr. Frederick Dixon in the year 1850,[1] who was most ably assisted in his palæontological researches by the most distinguished naturalists then living, each faunal group receiving critical supervision and description. A second edition of this valuable work appeared in 1878, wherein much new geological and palæontological matter is added. Both the Cretaceous and Tertiary reptiles were figured and described by Professors Owen and Bell, the fishes by Sir Philip Egerton, the Cretaceous echinodermata by Professor Forbes; Mr. Sowerby described the mollusca, the large crustacea were described by Professor Bell, and the corals by Lonsdale.

Selsea.

I now draw your attention to a locality of extreme interest both to the geologist and archæologist, and where cause and effect are manifested in both investigations, the historical portion being based upon physical causes and changes that have long been, and are still going on, to modify the form, extent, and structure of the Sussex coast, from the mouth of Chichester Harbour to Littlehampton and Bognor. In the year 1855 Mr. Robert Godwin-Austen, F.R.S. and G.S., read before the Geological Society an elaborate paper upon the 'Newer Tertiary Deposits of the Sussex Coast,' in which he also noticed some peculiar features in the parts of the Isle of Wight and South Hants bordering the Solent.

From Beachy Head to Selsea Bill, the coast line lies east and west, so that

[1] *The Geology and Fossils of the Tertiary and Cretaceous Formations of Sussex.* By F. Dixon. 1st ed. 1850, 2nd ed. 1878.

there intervenes a tract between the chalk range and the sea, which ultimately acquires a width of ten miles, as from Lavant to Selsea. This tract is low and level, presenting a series of superficial accumulations, remnants of a definite Tertiary period, of which at no other place in England is there any such record, and to which I ask your attention should any journey to inspect the phenomena exposed along the shore of Bracklesham Bay, or between Wittering and Pagham Harbour, or Bognor be proposed. Especially may I refer to interesting evidence as to local conditions during the glacial period. It may not be known to many, or all present, that the peninsula of Selsea is celebrated in English history as one of the places where Christianity was first taught in this country. It was one of the most ancient Saxon establishments. This peninsula was granted by Edilwalch, King of the South Saxons, to Wilfred the exiled Bishop of York, about the year 680. At that time it is stated to have contained 5,220 acres of land, with 85 families and 250 slaves. The parish now contains only 2,880 acres; 2,340 having been slowly denuded away by the action and encroachment of the sea. This encroachment and destruction during the past 800 years has been very extensive.

The creek called Pagham Harbour, on the south-east side of the Bill or peninsula, was due to an irruption before the year 1345, when 2,700 acres of land were destroyed. The site of the ancient cathedral and episcopal palace of Selsea, believed to have been situated to the south-east of the present church of Pagham, is no longer to be determined, but there is no reason to doubt but that it stood nearly a mile out in what is now sea. Camden, in his 'Britannia,' states that 'in this isle remaineth only the dead carkase as it were, of that ancient little citie (where those bishops (of Selsea) had their seat), hidden quite with water at every tide, but at low water evident and plain to be seen.'

The Bishop's Park, as the shore and sands are still called, extended for many acres on the south-east coast, and the remaining fragment has still the name of Park Coppice. The sea has gained more than a mile on this coast since the see and cathedral of Selsea was established A.D. 680; Wilfrid was the first Bishop of Selsea in that year, and Stigand was the first Bishop of Chichester A.D. 1070. No less than twenty-two Bishops had occupied the episcopal chair of Selsea, and resided there, before the removal to Chichester. The parish that divides Selsea from Bognor is called Pagham, and the extensive estuary, which is a mile long and broad in places, Pagham Harbour. The remarkable church is dedicated to St. Thomas à Becket, and the ruins of the archiepiscopal palace are still visible south-east of the church. Archbishop Becket resided here with a large retinue, and his interference with a manor within this lordship gave rise to his dissension with Henry II. which terminated in his assassination. That part of the coast marked 'the Park,' now covered by the sea, was part of the prelate's extensive estate, and is still visible at low water. The houses of the village are built of an arenaceous limestone almost entirely made up of microscopical shells, of the genera *Miliola* and *Alveolina*. This stone was formerly procured abundantly from an extensive range or ledge of rocks (called the Clibs and Mixen) south of Selsea Bill, and extending some distance east and west. In 1830 the removal of this bed of stone was forbidden, forming, as it did and does, a barrier to the encroachment of the sea.

This digression and somewhat archæological dissertation is necessary for my purpose, when drawing your attention to those recent geological changes that have taken place along that coast almost within modern times.

Thorney, Ham, and Medmeney marshes, behind Bracklesham Bay, and between Bracklesham and Selsea, are of marine or estuarine origin, separating Selsea from the mainland, making it what its name expresses, an island, 'Seles-eu,' or 'Island of the Sea-calf.' We are thus led to believe that when Selsea became known to the English nation it was an island, and that in Bede's time the process of silting up the estuary must have commenced, and the completion of this process would seem to have been before the Conquest. The action of the tides on this coast carries the sand and shingle from west to east, therefore the gradual wasting which has taken place on the shore of Bracklesham Bay has served to supply a large portion of the material of which these marshes are formed.

The ground on which Selsea, Bognor, Littlehampton, Worthing, and other

places on the Sussex coast westward of Brighton are built, is of very recent formation, being composed of gravels, sands, and loam belonging to the post-Pleiocene or Pleistocene series. These superficial post-Pleiocene beds overlie the well-known Eocene series in patches, and contain a large fauna. No less than 66 genera and 142 species, chiefly mollusca, occur here. The remains of the mammoth or elephant (*E. primigenius*, or *antiquus*) occur in the muddy deposits [*mud-deposit*]. With these are associated marine shells of existing species, but some not known now as such on the Sussex coast. East of Bognor, at low tides, we have the remains of a sunken forest, and west of Selsea the trunks and roots of trees, &c., may be examined at low water. These trees in both areas are not fossilized, but evidently destroyed by the encroachment of the sea, probably since the time when 'the Park' existed. In July, 1877, Mr. H. Willett, of Brighton, obtained from the beach below high-water mark, near East Wittering, a large number of bones of rhinoceros associated with several species of land and freshwater shells of existing species. The bones lay in the midst of decayed trees in a peaty deposit beneath the glacial beds of Selsea. An almost perfect skeleton of the *Elephas antiquus* is in the Museum at Chichester, which was obtained from the 'mud beds' or 'mud deposit,' off Selsea Bill; multitudes of the shell *Pholas crispata*, occur in the same bed. Teeth of the mammoth have occurred in the 'mud-deposits' of Bognor, Littlehampton, and Worthing; and we have again the well-known 'Elephant bed' at Brighton, doubtless of the same age.

At the British Association meeting in 1851, Mr. Godwin-Austen, F.R.S., then president of the Geological Section, called attention to the evidence of repeated oscillations of level, of no very remote date, which were to be observed in parts of the coast of Cornwall, Devon, the Channel Islands, and the Cotentin, an area comprising the western opening of the English Channel. As before stated, the same distinguished physicist, four years later, in his paper 'On the newer Tertiary Deposits of the Sussex Coast,' exhaustively described the phenomena of the later movements of the land, and interchanges between the sea and the coast. The oldest of the newer-Tertiary deposits of the Sussex levels in ascending order is to be seen only at extreme low-water in Bracklesham Bay; thence eastward round Selsea Bill, as far as the entrance into Pagham Harbour.

This portion of the Sussex series forms the 'mud-deposit' of Mr. Dixon. Its character and composition distinguish it from the beds above. It is composed of an extremely fine tenacious dark grey sandy mud, which resists the action of the sea; it rests upon the well-known Eocene Nummulitic strata.

The thickness of this Lutraria clay or 'mud-deposit,' can only be estimated at low-water spring tides; in places it is from 18 to 20 feet thick; it increases seawards and passes away beneath the sea-bed. On the coast near Medmeney (west side of the Bill) the surface of this clay is occupied by the remains of a colony of *Pholas crispata*, which has burrowed into it. This species attains here to great dimensions, and from its restricted range and littoral habit serves to determine the level of the tidal waters at the commencement of the Selsea deposits. The relative age of this old estuarine deposit of Selsea is determined by its mammalian remains. Those of *Elephas primigenius* are tolerably abundant, and the interest attached to them is enhanced by the fact that they do not occur here as single and detached teeth, or portions of tusks (as occurs on the higher gravels), but so many parts have been found together as to leave no doubt but that entire skeletons still lie embedded in this deposit. The head with the teeth and tusks and numerous bones have been found in close juxtaposition, and are now placed in the Chichester Museum. No less than sixty-six genera and 151 species of mollusca have been found here, or thirty-three genera and eighty-nine species of gasteropoda, and thirty-three genera and sixty-two species of pelycipoda, have been obtained from the Lutraria clay or 'mud-bed.' I may mention, among so many, the rarer shells that occur:—

Cerithium reticulatum, da Costa. = *C. lima*, Brug.—A Spanish, Portuguese, and Mediterranean shell, comparatively recent within our area.

Fusus turricula (Pleurotoma).—A boreal Atlantic species, occurs in the Red Crag. Scarce in the Faluns and Bridlington.

Pecten polymorphus, Bronn.—Lisbon, Mediterranean, very rare fossil in Italian and Sicilian beds.

Tapes decussata, ranges south but not north of British Islands. Common in the Mediterranean.

Lutraria rugosa.—Algeria and Morocco (living), also Canaries. South of Spain and Portugal.

Syndosmya Boysii (Amphidesma).—Atlantic; rare; ranges to coast of Spain.

Pholas crispata, Linn.—Rare on south coast of England, a Scandinavian species, and is found in the Crag.

From 'the assemblage of mollusca, and the patch of *Pholas crispata* in conjunction with conditions of the deposit, we may infer that the relation of the land to sea-level was then much what it is now, or that these ledges of mud-beds in which this shell is found, then lay between tides.' Many of the bivalve mollusca (Pelycipoda) lived in and on this mud, which is evident from the position in which the shells are now found, especially the *Myæ*, *Lutrariæ*, and *Pullastra* (Tapes). 'This area,' according to the views of Mr. Godwin-Austen, 'must have been an enclosed salt-water lagoon. The list of shells must be considered a special one, the result of local conditions subordinate to, but indicative of, a much larger marine fauna which had its full development in some adjacent sea; and this fauna as a whole differed as much from that of the present Channel waters, as the fossil contents of the Selsea mud-deposits do from the mollusca now inhabiting the series of large creeks and lagoons extending from Fareham to Pagham.' As regards the molluscan fauna of Selsea, some of which, now found on the Sussex coast, are essentially southern and western, they do not range further north, or into the German Ocean area, and this southern relation of the fauna of the Lower Selsea deposit (*Lutraria mud-deposit*) is further strikingly illustrated by the presence of the before-mentioned two remarkable species, *Pecten polymorphus* and *Lutraria rugosa*, neither of which are now known to range further north than Lisbon. 'We therefore have indications of a warmer condition of the waters of the English Channel, which allowed southern forms to range to a more northern latitude than now, and then a limitation of these forms to the area where now found, or in the Sussex deposits.' The inference drawn by Mr. Godwin-Austen as to the manner in which the elephant's remains occur in this Lutraria clay is an obvious and an interesting one, as it enables us to arrive at a relative geological date, showing that the lower estuarine beds of Selsea and of the Sussex levels generally were contemporary with what is known as the period of the large mammalian fauna.

Overlying this Lutraria or mud deposit, there occurs a tough, calcareous, sandy clay, with chalk, and chalk flints—waterworn and of large size. This Yellow Drift clay is of marine origin, determined by the associated mollusca; Littorina and Mytilus being disseminated through the mass. This deposit occurs over the whole of the Selsea peninsula, and extends inland beneath the Sussex levels. Besides the large masses of flints and materials from the chalk, oolitic rocks, and chert-sandstone from the Upper Greensand, resembling that occurring at Lyme and Charmouth, there are other rocks which, from their 'ages, composition, origin, size, and condition,' render the mode of accumulation a problem of great geological interest. 'The rocks in question consist of grey porphyritic granites, red syenites, syenite, hornblendic greenstones, mica-schists, green fissile slates, masses of quartz from veins, siliceous sandstones,' such as occur in the Palæozoic series (Lower Silurian) of Normandy, micaceous sandstone with orthides, probably from the Devonian beds, and blocks of compact limestone, whether from the Devonian series of Devon or the Cotentin (France), is uncertain.'

In size these older rocks range from coarse shingle up to masses of 20 tons weight, the granitic rocks being the most numerous and of the largest dimensions. A mass of porphyritic rock was exposed near Pagham by coast-line denudation, measuring 27 feet in circumference. Whence came they, and how brought, or what the transporting agent beyond that of floating ice, we know not. I must refer you to Mr. R. Godwin-Austen's original paper for matter of the highest interest relative to the origin and history of the yellow clay and the conglomerate bed, and later deposits in Sussex, as well as other phenomena bearing upon the

present aspect of this singular area—a description of the complex nature of the structure of which would here be out of place. 'What was the condition of the English Channel as to its coast-line when certain marginal accumulations were being formed?' To answer this demands a profound acquaintance with the old physical geography of the district both of Northern France and Southern England.

The Brick-earth.—Above the yellow clay and mammalian gravels, the highest or uppermost deposit on the coast, there occurs a uniform bed of dark chocolate-coloured unstratified clay, averaging about 3 feet in thickness. This clay forms part of that great layer of earthy matter which overlies all the gravel and other beds of the Sussex levels, and is extensively used for brickmaking. This brick-earth is a subaërial deposit, probably occurring as the wash of a terrestrial surface under a greater rainfall than we have now. This deposit is conspicuously shown along the shore, and forms the low cliffs of Bracklesham Bay. To this period Mr. Godwin-Austen refers the '*Combe rock*' of Selsea. He then refers to the condition of the English Channel area, at the period of the Crag-deposits of the German Ocean. The author is disposed to the belief that this Channel area was mostly in the condition of dry land at the time that the area of the German Ocean was occupied by the Crag sea. The peculiar molluscan fauna of the Sussex deposits point to a limitation of a *marine province* in that direction, whilst their habits indicate at the same time shallow water and marginal conditions. The temperature of the water of the English Channel during the period of the *Elephas primigenius*, and its associates, was such as now occurs 12 degrees or nearly 800 miles further south. In 1871 Mr. Alfred Bell examined with great care the fossil contents of the Lutraria clay or mud-deposit; he has added materially to the hitherto published lists of contents of this deposit. The result proves it to be unique as regards the fauna. 'Of the 144 species of shells Mr. Bell states that 30 do not exist nearer than the West of England, the Channel Islands, North of Spain, 8 or 10 not passing this side or north of Gibraltar, all being littoral (or sub-littoral) species. As British Quaternary fossils 45 are peculiar to Selsea, and 20 others probably find here their earliest place in British geological history.' Numerically the contents of this mud-deposit are as follows: mammalia, 5 genera and 6 species; mollusca (bivalves), 33 genera and 62 species; univalves, 32 genera and 80 species; polyzoa, 2 species; crustacea, 8 genera and 10 species; echinodermata, 2 genera and 2 species; foraminifera, 9 genera and 10 species. Most of the fossils occur opposite Thorney coastguard station, where the Lutraria clay rises at intervals in low hummocks. The elephant remains appear to be those of *E. antiquus*. The tooth of *E. meridionalis* has also occurred here, an association resembling the Forest-bed of Cromer. In the Chichester Museum there exists the greater portion of a fine skeleton of *E. antiquus* obtained from this mud deposit.

I have thus dwelt at some length upon these post-Pleiocene or Pleistocene beds at Selsea, owing to their local interest, and hope by so doing to induce any present who may be interested in the Quaternary geology of the British Islands, especially that of Sussex, to visit Bracklesham Bay and Selsea, near to which we are now assembled.

The Eocene Formations of Selsea and Bracklesham Bay.

It is impossible to pass unnoticed the Eocene tertiaries that occur in Bracklesham Bay, the stratigraphical position of which has long been settled, comprising the middle portion or fossiliferous division of the Bagshot Series. The Bracklesham beds take their name from the Bay in which they are so characteristically developed, yet difficult to clearly understand. The main divisions extend from Wittering, on the west, to the Barn Rocks, east of Selsea Bill, a distance of seven miles.

The Hampshire basin alone, in England, contains the nummulitic series, no fossiliferous representative being known in the London basin.

About a mile to the east of Selsea Bill is situated the 'Park bed.' This Park bed is analogous or equivalent to the 'Calcaire grossier' of Grignon, in the Paris basin.[1] It contains thousands of Nummulina lævigata associated with Perna, Bulla, Cypræa,

[1] Four hundred species of Mollusca have been found in the French deposits.

Solen, besides the well-known coral Litharea Websteri. The Park bed is situated close to the shore, and is accessible at low water. It is here at low spring tides that the very recent post-Pleiocene beds may be seen overlying the Eocene deposits. At the Bill the Eocene beds are shown at low water in large detached portions called the 'Clibs,' the larger portion lying to the south-west, and the so-called 'Mixen Rocks,' marked by the 'Mixen Pole,' trend about a mile out in the sea. From these rocks, which extend a mile and a half east and west, and varying from 200 to 400 yards wide, is procured the Alveolina or foraminiferal limestone; the 'Clibs' rock contains scarcely any other fossil remains. The *Houngate* Rocks, the same as the *Mixen*, are situated opposite Old Thorney Station House, and visible at low water; they are nearly a mile in extent, and vary from 50 to 60 yards in width. Certain fossils have given names to the beds that range through the bay. The remarkable shells *Cypræa Coombii*, the great *Ceritheum* (*C. giganteum*), and *C. cornucopiæ*, *Venericardia planicosta*, *Turritella terebellata*, *Conus diadema*, &c., amongst many others, aid us to determine the beds stratigraphically; locally the 'Barn bed,' 'Palate bed,' 'Venericardia bed,' the 'Park,' &c., serve to mark horizons of importance.

Opposite the New Thorney Station are the Scrobicularia or Lutraria clays or mud deposits from which the elephant remains were obtained.

The Rev. Osmond Fisher, in his description of the 'Bracklesham beds' of the Isle of Wight basin, restricts the name to a group of strata rich in organic remains, the greater part of which are displayed at low water upon the shore at Bracklesham Bay in Sussex. He also includes under that name higher beds than any seen at Bracklesham Bay that occur at Stubbington and the New Forest. He groups certain strata which appear to intervene between the base of the Barton series and the highest beds at Bracklesham Bay on account of their containing an assemblage of fossils more akin to the fauna of the Bracklesham than the Barton.

'No marine fossiliferous beds are known *below the lowest* at Bracklesham Bay, until we reach the Bognor Rock of the London clay—at Bognor—except it be a thin stratum of clay at the very base of the Bracklesham series at Whitecliff Bay. The following shells range through the Bracklesham group, and are confined to it, viz., *Venericardia planicosta*, *Sanguinolaria Hollowaysii*, *Solen obliquus*, *Cytherea suberycinoides*, *Voluta cithara*, *Turritella sulcifera*, and *Pecten corneus*; the last-named species occurs in the High Cliff beds.' The Rev. O. Fisher, through the confined range of certain species, has divided the whole series into four principal groups. Vide 'Quarterly Journal of the Geological Society,' vol. xviii. pp. 66–75.

Group A The upper, abounding in gasteropoda, and has one of its fossil beds in the eastern part of its range full of *Nummulina variolaria*.

Group B is more sandy in its general condition, and distinguished by the presence of the large gasteropoda. *Cerithium giganteum*, *Nummulina variolaria*, occurs in this member at Whitecliff Bay.

Group C Sandy like the last, but its chief fossil-bearing bed is profusely crowded with *Nummulina lævigata*.

Group D embraces the lowest fossiliferous sands of Bracklesham Bay. The distinctive shells are *Cardita acuticosta* and *Cypræa tuberculosa*.

Bracklesham beds at Whitecliff Bay.—These beds rest on the Lower Bagshot sands, and agree with bed No. 6 of Professor Prestwich's section, their base being distinguished by a bed of rolled flint pebbles about 1 foot in thickness.

Reading in descending order Mr. Fisher's group A, including the beds xix., xviii., xvii., xvi., xv., xiv., and xiii., correspond with the beds numbered 17, 16, 15, and 14 in Professor Prestwich's; together they measure 254 feet. The position of the beds here renders them easily accessible at Bracklesham Bay, but they are nearly horizontal, and consequently must be paced to be understood. Beds No. xvii. and xiv. of Group A are the most fossiliferous, and both contain *Nummulina variolaria*.

Mr. Fisher's Group B includes beds xii., xi., x., and ix., or Professor Prest-

wich's No. 13. No. ix. of Fisher and 13 of Prestwich is the chief fossiliferous bed. *Nummulina variolaria, Voluta nodosa*, and *Sanguinolaria Hollowaysii*, are the chief fossils in this bed; the thickness of the group is only 27 feet.

Group C, with beds viii., vii., and xi., correspond to Professor Prestwich's Nos. 2 and 11. No. vii. contains the distinctive and characteristic nummulite, *N. lævigata*, also equally abundant at Bracklesham Bay with *Sanguinolaria Hollowaysii*. Bed No. vi. of Fisher, and No. 1 of Prestwich, is very fossiliferous. These 3 beds measure 123 feet.

Group D is composed of beds No. v., iv., iii., ii., and i., or Nos. 10, 9, 8, 7, and 6 of Prestwich. The only fossiliferous bed in this group is No. iv. of Fisher, and 9 of Prestwich, in which the great *Venericardia planicosta* abounds, as at Bracklesham Bay, the fine shell *Cypræa tuberculosa* not occurring at Whitecliff Bay. The beds comprising this group are 251 feet thick; in all, the Bracklesham beds at Whitecliff Bay measure 653 feet. I have deemed it important to partly particularize this remarkable section at Whitecliff Bay by way of comparison with the fine section shown at low water in Bracklesham Bay, where the beds occupy the shallow shore for 3½ to 4 miles, and are nearly horizontal, or dip S. by E., with a strike of W. by S. and E. by N. So nearly level are the beds, that there is no opportunity given to measure the dip or thickness with accuracy. Mr. Fisher, in his excellent section, has given the order of succession of the beds, and the distances between the outcrops. The beds exposed towards, or near Selsea Bill, belong to the upper members, and their strike is nearly tangential to the shore, consequently we continue our walk upon the same outcrop for a long distance in step-like planes. I give the Rev. O. Fisher's section and sequence round Selsea Bill as he observed them, as a guide to those who may visit the area. Vide 'Quarterly Journal of the Geological Society,' *loc. cit.*

Commencing at a spit of gravel seen at low water off 'the Bill,' brought together by the meeting of the tides from the 'Park' and Bracklesham Bay, and going westward or towards Wittering, we have the following ascending section:[1]—

	Paces
'Beds then covered with sea sand	600
Outcrop of septaria, on sandy clay weathered green beds covered with sea sand	127
Hard dark grey, sandy bed, nummulitic in upper part (nummulites abundant at 216 paces, concretions at 226 paces)	420
Nummulina variolaria, and other foraminifera in clay	324

'Taking up this last-named bed again as being *the highest distinguishable* at this place, we then have the general descending series along nearly 3 miles of the shore' westwards.

Descending Section of Bracklesham Beds at Bracklesham Bay.

		Paces
A	22. Clay—*Nummulina variolaria, Alveolina sabulosa, Quinqueloculina, Hawerina, Biloculina ringens, Rotalia obscura, Turbinolia sulcata*, &c.	324
	21. Hard calc. sand; 'HARD BED' foraminifera, *Tellinæ*	140
	20. Greyish clay with *Corbulæ* and *Nummulinæ*	120
	19 (*d*). Dark clay (Cypræa bed, Dixon)	460
	18. Sandy clay containing same shells as 19(*d*)	66
	17. " " green foss. in upper part	194
	Pleistocene mud[2]	112
	Green sandy clay	300

[1] Every yard of this bay and its extended beds were measured and paced, and the map constructed by Mr. Bristow and myself, and the fossils observed in the numerous thin beds comprising the section.

[2] These clay beds are nearly modern in age, and cover up unconformably the underlying Bracklesham beds.

		Paces
B	16 (*e*). Sand full of casts, bivalves	218
	Pleistocene mud[1]	80
	15. Hard sand, weathered green	70
	14. Shelly sand, greenish-brown, full of fossils, *Cerithia* and *Cytherea striatula* (Little bed)	29
	13. Dark sandy clay with *Turritella imbricata*	240
	Pleistocene clay, laminated, with *Ostrea edulis*, &c.[1]	124
	12 (*f*). Dark clayey sand with numerous *Cerithium giganteum*, *Pectunculus pulvinatus*, &c. &c.	163
	11. *Septaria*, resting on shelly sand with black flint pebbles	150
	10. Laminated liver-coloured clays, sandy towards the bottom	246
	9. *Ostrea tenera* bed, 18 inches thick	52
	8. Dark green sand, full of broken shells, *Pectunculus pulvinatus*, *Lucina*, *Bulla Edwardsii*. Towards upper part (79 paces less). Shelly in the middle (48) abounding in *Turritella terebellata* at the base	175
	7. Soft laminated dark-coloured clay	177
	Pleistocene mud, out of which in places protrudes a clay weathered green[1]	288
C	6 (*g*). *Nummulina lævigata* bed, with numerous fossils (Little Park bed)	40
	5. Sandy clay, weathered green	107
	Beds covered partly with sea-sand and partly with Pleistocene mud	105
	4 (*h*). Dark mottled sandy clay, shells and scattered nummulites, *fish* and *serpent* remains ('Palate bed')	134
	Covered with sea sand	96
	3. Dark sandy clay	53
	„ „ „ with broken shells	111
	Covered	30
D	2. Turritella bed, *T. imbricataria* and *T. sulcifera*	92
	1. Septaria containing shells and occasionally *Rostellaria ampla* (68 paces), resting on a mass of *Venericardia planicosta* and *C. acutirostra*; the lower part of the bed is Greensand crowded with shells, among which, immediately beneath the *Carditæ*, the *Cypræa tuberculosa* occurs. The bed then becomes less fossiliferous, and passes into a dark grey laminated clay, broken up and re-arranged, mixed with dark sand and black pebbles ('Barn bed,' Dixon)	330
		5,016

Below this no fossils found.

The Park on East side of Selsea and the Mixen Rocks.

On the east side of Selsea peninsula, the highest bed seen is the *Nummulina lævigata* bed, rich in fossils. All the succeeding beds down to the *Venericardia planicosta* bed are usually exposed at 'the *Park*.'

Mixen Rocks.—A ledge, one mile south of Selsea Bill, composed of a *Miliola* and an *Alveolina*, continuation of No. 22(*b*) only more calcareous.

Bournemouth Area.

The geology of this remarkable area has received attention from several explorers: Sir Charles Lyell in 1826, Professor Prestwich in 1848, the Rev. O. Fisher in 1861; and in the year 1878 Mr. John Starkie Gardner prepared and read an able paper on the 'Description and Correlation of the Bournemouth Beds,' Part I.;

[1] These clay beds are nearly modern in age, and cover up unconformably the underlying Bracklesham beds.

the Upper Marine Series,[1] treating of the coast section between Bournemouth and Highcliff; and a second paper, Part II., on the lower or Freshwater series.[2] He states his reason for differing from the previous writers upon the succession of the beds and their correlation with other localities. Mr. Gardner's researches are intended to show that the celebrated Bournemouth leaf-beds immediately underlie the true Bracklesham series, and are, unlike those of Alum Bay, of *Middle* and not of *Lower Bagshot* period, hitherto the received view as to their age. The author has also ascertained that a great portion of the cliffs between Hengistbury Head and Bournemouth are of marine origin, and highly fossiliferous. These marine beds comprise two distinct characters, which the author traces across to Alum Bay in the Isle of Wight. Mr. Gardner also differs from the Geological Survey in believing 'that the so-called Upper Bagshot beds of the London basin do not belong to that series, but are the equivalents of his Boscombe sands; these sands, and the marine Bournemouth beds being, according to his researches, the western equivalents, or extreme shore-condition of the Bracklesham sea.'

At Highcliff, nearly under Rothsay Castle, both the Barton and the Bracklesham series are exposed, the Barton being not more than 10 feet in thickness, and the subjacent Bracklesham 40 feet. The section is revealed to the sea-level, and therefore highly instructive. The Highcliff sands conformably underlie the Barton and Hordwell series at an angle of 2° to the E. The remarkable promontory of Hengistbury Head is mainly composed of strata contemporaneous with the Bracklesham series; these Mr. Gardner would for convenience call the] Bournemouth beds. Hengistbury promontory in shape resembles a parallelogram obliquely truncated at its northern extremity. The cliffs facing the sea on the south are about 50 feet high, increasing to 100 feet on the north, both presenting bold escarpments to the sea. 'The succession of the strata at Hengistbury Head, reading upwards, comprises, 1, the Boscombe sands; 2, a lower series of sand with green grains, and an upper bed with ironstone; and 3, the white Highcliff sand. The white sands at Highcliff are 30 feet thick, being 12 feet thinner than the equivalent beds at Alum Bay, where they measure about 42 feet.' The lowest series in the cliffs at the headland Mr. Gardner terms the 'Boscombe sands,' which without any doubt represents the chief mass of brilliantly coloured sands, about 750 feet thick, at Alum Bay, known to all explorers of the island. These coloured sands are numbered 25 and 26 in Professor Prestwich's section of the vertical beds in Alum Bay.[3] Mr. Gardner also notices another hill similar in contour to that of Hengistbury, about three miles to the north of the Head. This, St. Catherine's Hill, possesses, like the headland, similar physical features, being flat-topped and having abrupt escarpments on all sides, and 160 feet high. Both the Highcliff sand and the Hengistbury beds occur in this hill, showing their connection and continuity inland with the coast section. 'The correlation of the Hengistbury Head series on the mainland with those of Alum Bay across the Solent admits of little doubt, and they would appear to be represented at Alum Bay by the *Highcliff sands*, 25 feet in thickness, and equivalent to bed No. 28 in Professor Prestwich's section. The Hengistbury Head beds appear to be the equivalents of bed No. 27 in the Alum Bay section. The Boscombe sands represent beds No. 26 and 25 of Prestwich in Alum Bay, where they are 150 feet thick. It can be conclusively seen, from examination of the cliffs in the Bay from Hengistbury to Bournemouth, that there is a general sequence, and that the strata have an amount of dip or inclination sufficient, in so extended a distance, to expose two complete series of beds, the upper series being the continuation of the Boscombe estuarine sands, 100 feet thick, and the lower series of sands and clays, of marine origin, which Mr. Gardner has provisionally termed the Bournemouth marine beds.' With Mr. Gardner's paper in hand the most minute details of the coast may be followed,[4] from the Head towards Bournemouth. These, both for physical and palæontological details,

[1] *Quarterly Journal of the Geological Society*, vol. xxxv. pp. 202–228.
[2] *Quarterly Journal of the Geological Society*, vol. xxxviii. pp. 1–15.
[3] *Quarterly Journal of the Geological Society*, vol. ii. pp. 223–259.
[4] *Loc. cit.* pp. 217–226.

I must therefore refer you to, as giving step by step an analysis of the structure of the cliffs, and the flora contained in the clays and sandy series of which they are composed. This flora of the Bournemouth marine beds may be referred to the Middle Bagshot series, and the Bracklesham division, possibly representing the same stage in the London basin, and it would appear from careful consideration of the Middle and Upper Bagshots that no Eocene beds younger than the Bracklesham are met with in the London area, a geological fact of much significance as compared with the complete succession of the Eocene series as developed in the Hampshire basin, and that of their equivalents in the basin of Paris. Mr. Gardner believes that 'the fossil plant remains of the Bournemouth beds, especially those in the marine series, are of the same age as those in the Bovey Tracey deposits, which have been wrongly assigned to the Miocene period, believing, in fact that they are simply an outlier of the Bournemouth series, now 80 miles to the west,' but formerly and originally connected as a western extension of the Bournemouth deposits.

Comparison of the flora of the two areas shows a close affinity, if not identity of species, *Osmunda lignata, Lastræa Bunburyi, Palmacites dæmonorops*, the fruits, conifers, and dicotyledons being not only specifically identical, but occur in the same combinations and manner of preservation,' *loc. cit.* pp. 227, 228. *Polypodium, Chrysodium, Pteris*, and *Osmunda*, amongst the ferns; *Eucalyptus*, branches of Sequoia, pods and leaves of the Leguminosæ, *Nipadites, Dryandra, Cacti, Anona, Hightea*, &c. occur in the beds constituting the western termination of the Bournemouth marine series. The fauna testifies to its marine derivation by the genus *Ostrea, Arca, Modiola, Tellina, Calyptræa, Phorus, Natica*, and *Cerithium*. The crustacea, through *Callianassa*, and a shore crab, with Bryozoa (Flustra), need no other comment. The changing physical characters of the beds of the Bournemouth series, both horizontally and vertically, the marshy character of the flora, 'as represented by the ferns, aroids, Eucalyptus, &c., the patches of clay, in which the water-plants, ferns, &c. may have rooted, the local patches of ironstone, the intercalated marine beds and their fauna, mingled with unios, clearly shows that this was the debateable ground between sea and river, beyond which to the west it would appear the sea never then penetrated.' In February of the present year, Mr. Gardner communicated to the Geological Society his second paper on these Bournemouth beds, being a continuation of his former notice, but in this his researches are confined to the history of the 'Lower or Freshwater Series'[1] of the Bournemouth area. The author describes the geological structure of the Eocene cliffs as far as Poole harbour. All the strata between Bournemouth and Poole harbour are of freshwater origin, and highly interesting on account of the fossil flora recently obtained from them by Mr. Gardner—undoubtedly the most extensive, richest, and most varied hitherto discovered or extracted from the Tertiary formations. No less than nineteen species of ferns have been described from these beds. Only ten species have been met with in all the other British Eocene deposits, including the famous Bovey Tracey beds, and three of these ten are also found at Bournemouth. Sir C. Lyell, in 1827, the Rev. P. B. Brodie, in 1842, Mantell, in 1844, Prof. Prestwich, in 1847, Trimmer, in 1855, De la Harpe, in 1856, and Heer, in 1859, have all written upon the flora and its associated conditions, origin, &c. In 1862, the Geological Survey, through the Memoir by Forbes and Bristow upon the Isle of Wight, held the view that the fossil flora of Bournemouth, Corfe, and Alum Bay, were identical, although few species were common to these localities. 'The cliffs comprising the Bournemouth freshwater series extend from Poole harbour on the west, to beyond Bournemouth, and present escarpments averaging about 100 feet in height, composed of yellow, white, orange and black sands and clays, crowned with fir-trees or pine woods.'

Mr. Gardner places these Bournemouth beds in the Middle Bagshots, drawing the line between these and the Lower Bagshots at the pipe-clay beds of Corfe, Studland, and Alum Bay in the Isle of Wight. This line of division is drawn on account of the great dissimilarity of the flora contained in each. The Bournemouth flora, which is distinct from the older, or Alum Bay series, passes up into the so-called

[1] *Quarterly Journal of the Geological Society*, vol. xxxviii. p. 1.

Oligocene without any perceptible change or break; but few, or none, of the same species pass down or occur with the Alum Bay beds.

These Middle Bagshots are represented in Alum Bay by the unfossiliferous beds marked 19 to 24 in Professor Prestwich's section,[1] and are 240 feet thick. Palæontologically, these beds may be correlated with the continental Eocenes, probably those of Aix-la-Chapelle. The cliffs fronting the sea may be divided into three groups. The first extends from Poole Harbour to Bateman's Chine, the second group extends from the Sugar-loaf Chine to Watering Chine, the third section or group extends from Watering Chine to the Bourne Valley.[2] The chief interest attached to the Bournemouth beds is the flora distributed chiefly through the '*Lower or Freshwater Series.*' None of the prevailing Alum Bay types are found at Bournemouth, nor are any of the well-known Bournemouth types found at Alum Bay, and according to Mr. Gardner, their affinities are completely with the floras ascribed in France to the Oligocene, and the forms of flora as at present known, chiefly Australian and tropical American.

The author has endeavoured to show that 'a great river existed throughout the whole of Eocene times, bringing deposits from the westward, and that the Bournemouth cliffs present a section across its bed, these deposits being formed during a continued period of subsidence.' 'The sudden change observed in the beds from fine to coarse sediment, and the thickness of the deposit, cannot be explained by the floods and freshets incidental to changing seasons, but are such as would occur whenever subsidence exceeded, in however trifling a degree, the silting up power of the river,' *loc. cit.* p. 13.

It is a question of importance whether the continental floras similar to our own at Bournemouth have been correctly determined. 'For while all the strata that have yielded dicotyledonous leaves or fruits below our Headon series are admitted to be Eocene, scarcely any of the beds on the Continent resembling them are ascribed to that age,' but to the Miocene. 'For as all Eocene floras approximate more or less to Miocene, it has been a kind of rule in the absence of stratigraphical evidence, to assume that all isolated patches with dicotyledons, belonged to the latter period,' and had the stratigraphical evidence at Bournemouth been inconclusive, the whole of that Eocene formation must also upon plant evidence (for we have no other) have been classed as Miocene.

The *Lower Freshwater series* is seen in the neighbourhood of Corfe and some parts of the cliffs at Studland. It is characterised by abundance of pipe-clays, and is about 200 feet thick.

The *Middle Freshwater series* also occurs at Corfe and Studland, and forms the whole thickness of the cliffs between Poole Harbour and Bournemouth, thus constituting a fine section, 4 miles long and 100 feet in height.

The next series is marine, and about 400 to 500 feet thick. This marine group occupies the cliffs between Boscombe and High Cliff.

The Bournemouth flora appears to consist principally of trees or hardwood shrubs, few remains of herbaceous plants being preserved. The ferns are rare in the lower part of the series, but become more abundant, almost to the exclusion of other vegetation, towards the close of the middle period.

The prevailing group appears to be that of Acrostichum, of which there were many species. *Angiopteris, Nephrodium, Gleichenia,* and *Lygodium*, and other undescribed forms occur.

Among the *Coniferæ, Cupressus, Taxodium,* and *Dacridium*, with indications of pinus. The Cycadæ seem to have disappeared.

The monocotyledons are well represented by reeds and rushes. *Nipadites* represents the screw pines. The palms are very abundant, especially in the lowermost beds of Corfe and Studland and the upper middle beds of Bournemouth; many *Flabellaria, Sabal,* and *Phœnicites* occur; the Smilaceæ occur in all the fossiliferous beds, and are represented by five or six species.

[1] *Quarterly Journal of the Geological Society*, vol. x. p. 56.
[2] For particulars of these three groups, see *Quarterly Journal of the Geological Society*, xxxviii. pp. 5–8.

The Apetalæ, illustrated by *Populus, Ulmus, Laurus, Quercus, Artocarpidium,* and *Daphnogena,* with *Carpinus, Fagus, Castanea, Salix,* and *Ficus,* and numerous Proteaceæ.

Elæodendron, Rhamnus, Prunus, Juglans, Cluytia, Ceratopetalum, with *Dodonæa, Celastrus, Eucalyptus,* and many *Leguminosæ,* illustrate and characterise the Polypetalæ.

Cactus and *Stenocarpus* are added for the first time to the Eocene dicotyledons.

Mr. Gardner believes that we have probably represented almost every genus descended from Continental floras.

The Eocene flora presents us with types peculiar to the Southern Hemisphere, and related to those of Australia and the adjacent islands. We have examples of this southern flora through the *Proteaceæ, Leguminosæ, Coniferæ,* and the *Myrtaceæ,* through *Eucalyptus.*[1]

ISLE OF WIGHT.

The present rhomboidal form or configuration of the Isle of Wight is due partly to the unequal action of the sea on its coast line, and partly to those disturbances or movements which have thrown some of its strata into the positions exhibited at Scratchell's Bay, Alum Bay, and Whitecliff Bay.

The rapid waste of the cliffs going on at Sandown and Freshwater Bays is due to the action of the sea, the Lower Greensand and Wealden strata there exposed being more easily destroyed than the chalk.

The leading physical feature in the structure of the Isle of Wight consists in the ridge of high and bare chalk downs near the centre of the island extending from the Needles on the west to Culver Cliff on the east. Another chalk range parallel to the former, but on the south of the island, extends from St. Catherine's Down on the west to Boniface Down on the east. In the space occupied between these two chalk ranges (upper cretaceous rocks), there occurs the complete succession of the lower cretaceous and lacustrine Wealden groups, comprising the Hastings sand and Weald clay exposed at Compton Bay and Rock Point on the west, and Sandown Bay on the eastern side. The central ridge is depressed and cut through by transverse valleys; such occur at Freshwater Gate, Shalcombe, Calbourn, and by the Carisbrook, Medina, and Brading valleys. 'All these breaks may possibly be on lines of faults running or cutting through at right angles to the strike of the chalk.'

The part of the Isle of Wight which lies to the north of the central chalk range is entirely composed of the older Tertiary or Eocene strata. The only fault of magnitude known in the island is that occurring along the line of the Medina valley. Those on the eastern side of the river are the Headon, Osborne, and St. Helen's series. The rocks at West Cowes, or west of the Medina, belong to the Bembridge marls or fluvio-marine series. 'From the known thickness of the several groups the amount of displacement which takes place on the line of fault between East and West Cowes, or along the line of the Medina, cannot be less than 200 feet.'

The longitudinal undulations affecting or disturbing the Tertiary strata north of the chalk ridges are less obvious than those above described. The chief flexures which are in immediate sequence with the chalk are exhibited both at Whitecliff and Alum Bays, where the Lower and Middle Tertiaries are inclined at very high angles.

The first set, or the east and west undulations, are connected with the movement that elevated the chalk vertically. The north and south undulations also affect the chalk, since each north and south valley formed by the synclinal curve or hollow of the roll, corresponds to the division between the two chalk downs, and each down to an anticlinal. All the Lower Tertiary strata, including the fluvio-marine beds, are affected by these movements.

[1] Mr. Gardner has been greatly aided in his floral researches by Baron Constantin Ettingshausen, Ph.D., who has brought to bear his great knowledge of fossil plants and their distribution through the higher Tertiaries. The joint monograph by Messrs. Gardner and Ettingshausen on the 'British Eocene Flora,' in the Palæontographical Society's volumes for 1879 is of the highest value to Palæobotanical students.

The gravel beds, which rest upon the older Tertiary strata, whether the oldest or higher level gravels, or the newer, such as those which occupy the combes and transverse valleys, are unaffected by these movements, showing that their origin is subsequent to the disturbing forces which affected the Secondary and Tertiary rocks below them or on which they rest.

Lower Tertiary Strata of the Isle of Wight.

The Lower and Middle Eocene strata of the Isle of Wight, especially up to the base of the fluvio-marine series, may be better studied in the cliffs in Alum Bay and Whitecliff Bay than in any other part of the island.

In these remarkable sections the whole of the strata from the chalk to the fluvio-marine formation are displayed in unbroken succession.

Plastic Clay.

'The lowest member of this group of strata in the Isle of Wight is the Plastic Clay, or Woolwich and Reading series of Mr. Prestwich.' These beds are best examined in Whitecliff Bay and Alum Bay, especially the former, where the mottled beds are well exposed. No fossils have occurred in the plastic clay of the island. Seven beds have been recognised, the whole measuring 85 feet; they constitute a narrow belt striking across the island, resting on the chalk.

The London clay succeeds the plastic clay, and also forms a narrow belt extending across the island from the west coast at Alum Bay to the east at Whitecliff or Culver Cliff; its thickness is about 200 feet. A band of flint pebbles only 2 inches thick divides the plastic clay from the London clay, representing the basement bed of Mr. Prestwich. Nowhere in Britain can the London clay be so advantageously studied as at Whitecliff Bay, or where the characteristic fossils are better exposed. Twenty-five to thirty characteristic species may be collected here. Amongst others may be named *Pinna affinis*, *Pectunculus brevirostris*, *Pholadomya margaritacea*, *Panopea intermedia*, and *Modiola elegans*. The annelide *Ditrupa plana* belongs essentially to the London clay.

Middle Eocene.

Lower Bagshot Beds.

Joshua Trimmer, in 1850, first applied the term Bagshot to the whole series of strata in Alum Bay and Whitecliff Bay, dividing it into upper, middle, and lower, thus correlating it with the corresponding series in the London area which had been previously established by Professor Prestwich.

The Lower Bagshot beds are greatly developed in the Isle of Wight, attaining a thickness in Alum Bay of 660 feet, the most important genera being Elæodendron, Taxites, Quercus, Juglans, Daphnogene, Laurus, Cæsalpinia, Cassia, Ficus, Dryandra, Rhamnus and Sabal, &c. They comprise a series of variously-coloured unfossiliferous sands and clays, with accompanying iron-sandstone and clay. These last beds are in one place crowded with the leaves of sub-tropical land plants illustrating no less than 19 families, 26 genera, and about 50 species: the *Araliaceæ*, *Casuarinaceæ*, *Celastraceæ*, *Coniferæ*, *Cornaceæ*, *Cunoniaceæ*, *Cupuliferæ*, *Cycadæ*, *Ebenaceæ*, *Euphorbiaceæ*, *Juglandæ*, *Laurineæ*, *Leguminosæ*, *Moreæ*, *Palmæ*, *Proteaceæ*, *Rhamneæ*, *Sapindaceæ*, and *Tiliaceæ*. The same strata at Bournemouth and Corfe Castle in Dorsetshire exhibit an identical but also richer flora. Out of the great series found at Bournemouth through the researches of Mr. J. Gardner, fifteen or sixteen species occur in the pipe-clays of Alum Bay. As a whole they indicate a rather high temperature. The flora of the Lower Miocene beds, well known in Central Europe, has some affinities with that of our Hampshire basin.

The tropical or sub-tropical character of the London clay plants was long ago worked out by Dr. Bowerbank, but it was reserved for Dr. De la Harpe to carry his comparison into the Middle Eocene beds, and to show that there had been only a moderate decrease of temperature, so far as plants could show, in the time occupied by the deposition of the Bagshot or Bracklesham sands. The marine fauna of the same period fully bears out this conclusion, there being no essential difference between the fossils of the London clay and those of the Bagshot, or even the Barton beds, which would indicate a marked change of climate.

The flora of the Alum Bay beds is especially distinguished by the number and variety of its Leguminosæ. The plant-contents of the Lower Bagshot beds of Alum Bay approximate to that of the London clay by the predominance of plants of this family, forty-seven species of which were obtained by Mr. Bowerbank.

The junction between the London clay and the Lower Bagshot is clearly seen in Whitecliff Bay, the brown ferruginous clay representing the former, and the latter being represented by pale grey or white sands about 40 feet thick. In the 640 feet of these Lower Bagshot beds at Alum Bay no other fossils are known than plants, and about 60 species occur.

Middle Bagshot Series.

Bracklesham Beds.

The strata comprised between the sands at the base of Headon Hill, and the pipe-clay bearing sands and clays (Lower Bagshots), overlying the London clay, are subdivided into Barton clay and Bracklesham beds. The Bracklesham beds in Alum Bay are represented by clays and marls in the lower part, and by white, yellow, and crimson sands above. The lower beds are remarkable for the quantity of lignites, coaly or vegetable matter contained in them, constituting beds from 15 inches to 2 feet in thickness. The black and coal-like appearance of four of these beds are conspicuous and marked objects in the cliff, and determine the position of the Bracklesham series.

The uppermost beds of the series, or the yellow, white, and crimson sands, are unfossiliferous. At Whitecliff Bay the lower part of the Bracklesham beds are green, clayey sands, containing *Venericardia planicosta*, *Turritella imbricataria*, and *Nummulites lævigatus*. Six zones of fossils are there recognised. A hard bed of conglomerate composed of rounded flint pebbles in a ferruginous cement is also a marked feature in the cliffs at Alum Bay, defining the division between the Bracklesham beds and the overlying Barton clay.

Barton Clay.

The Barton series, composed of sandy clays and sands with layers of septaria, is sufficiently shown in Alum Bay, where it attains a thickness of 300 feet, and is rich in fossil remains, the whole of which are marine; 48 genera and 90 species of mollusca alone have occurred at Alum Bay.

At Barton Cliff, on the mainland, or opposite coast of Hampshire, a rich and abundant marine molluscan fauna occurs. The lower beds at Alum Bay contain *Voluta luctatrix*, *Rimella* (*Rostellaria*) *rimosa*, *Conus* or *Conorbis dormitor*, and *Fusus longævus*, with *Crassatella sulcata*, &c.

Upper Bagshot Sands.

These are the unfossiliferous sands below the Lower Headon beds, used extensively for glass-making, which may be 150 feet thick at Alum Bay. In Whitecliff Bay the junction between the Upper Bagshot sands and the Barton clay is sharp and well-defined; a few casts of fossils occur here, but in so friable a state that they cannot be removed.

Examination of the cliffs at Alum Bay will at once show that the strata from the chalk to the Upper Bagshots are highly inclined, caused by the force that produced the anticlinal axis which traverses the island east and west, and this axis brings to the surface the Wealden beds in Brixton and Sandown Bays, thus revealing the extent and continuity of the Wealden series, and determining its presence westward in the Isle of Purbeck along the same east and west line of elevation. Eastward of the Isle of Wight this axis is lost under the waters of the English Channel, and we have no visible proof of its influence towards Beachy Head; it may have aided in preparing a weakened line for the course of the Channel towards the Straits of Dover. These beds at Hordwell Cliff have been the subject of a notice by Mr. Tawney in the 'Proceedings of the Cambridge Philosophical Society,' and will be referred to in the latter part of my address.

Headon Series. 170 feet thick.

Best seen at Headon Hill, Colwell Bay, and at Whitecliff Bay, and their lowest divisions at Hordwell. Everywhere *Planorbis euomphalus* characterises the freshwater bands.

Potamomya plana and *Cerithium pseudocinctum* abound in the brackish-water beds. *Cytherea* (*Venus*) *incrassata*, accompanied by many shells, occurs in the marine division.

The group may be divided into three sections: Upper, Middle, and Lower Headon.

Upper Headons.—These constitute the greater portion of the *Upper Freshwater* series. The mass of freshwater limestone in Headon Hill belongs to this section. Brackish in the upper part, abounding in *Potamomya* and *Cyrena obovata*, at Cliff End they contain a *Cyrena* (like *C. pulchra*). *Cerithium trizonatum* occurs here abundantly, and *Bulimus politus* and *Melania muricata* abound.

Middle Headons. '*The Headon intermarine or Upper marine formation.*'—At Headon Hill these deposits were deposited under brackish-water conditions, for, although *Ostrea*, *Cytherea incrassata*, *Nucula deltoidea*, *Natica depressa*, *Buccinum labiatum*, and other sea-shells are common, the upper and lower beds abound in *Cerithium ventricosum*, *Cerithium concavum*, *Cerithium pseudocinctum*, *Neritina concava*, *Nematura*, *&c.* which are brackish or estuarine. A short distance further north, in Colwell Bay, the upper and lower beds contain brackish-water shells; but the central part assumes a distinctly marine character. *Ostrea velata*, S. Wood, is a characteristic species with numerous marine genera, many of which are of Barton types. This central part is known as the '*Venus bed*,' from the presence of *Cytherea incrassata*. The marine character of the *Middle Headon beds* is still more strongly marked at Whitecliff Bay (22 genera). The lower portion of this series at Whitecliff Bay contains many Brockenhurst species, but at Colwell Bay we have no evidence of characteristic species from this last horizon, or in the western side of the island.

Lower Headons, fresh and brackish-water series.

These beds are 70 feet thick in Totland Bay, and 40 feet thick in Whitecliff Bay.

They consist of fresh and brackish-water beds abounding in fossils resembling those of the upper division. *Unio Solandri* and *Cyrena cycladiformis* occur here and are characteristic.

At Headon Hill the thick bed of limestone in the Upper Headon is conspicuous in the cliffs, but it thins out rapidly towards the north and disappears in an easterly direction. The Lower Headon contains a much less thick limestone at Headon Hill, and it is represented by the band forming How Ledge between Colwell and Totland Bays. 120 species have been obtained from the Headon series: 104 mollusca, 9 crustacea, 4 annelids, and 3 plants. Land, freshwater. and marine the fossils of the Headon fluvio-marine series, are $\frac{23}{74}$ gasteropoda, $\frac{15}{25}$ pelycipoda; polycipes 1, balanus 1, crustacea $\frac{5}{9}$, plantæ $\frac{2}{2}$, fish $\frac{2}{2}$ (the upper figures denoting genera, the lower species).

The St. Helen's Beds, or Osborne and St. Helen's.

Between the Bembridge limestone and the brackish-water beds with *Potamomyæ*, that terminate the Headon beds, a considerable series of strata intervenes, which on account of their mineralogical and palæontological peculiarities, deserve to hold an intermediate position between the middle and upper Eocene strata, and have been named the Osborne Series. Among the fossils are *Paludinæ* (*P. lenta*), *Melaniæ* (*M. costata, M. excavata*), *Melanopsis brevis* and *M. carinata*. *Chara Lyellii* is the Gyrogonite of the limestone band, which on the east side divides the Upper or St. Helen's sands from the Lower or Nettlestone beds. The difference between the upper and lower portions of them is considerable.

Osborne Series in Whitecliff Bay.

Thickness 100 feet.—Dark red clays and bright red and variegated clays occur. (*Helix occlusa*, *Planorbis discus*, and *Lymnæa longiscata*.)

Osborne Series between St. Helen's and Ryde.

Between Brading Harbour and Ryde, sections occur, and on shore are seen the rocky ledges below Seafield, and from St. Helen's to Nettlestone. At Watchhouse Point, below St. Helen's, the Bembridge limestone forms an extensive arch.

Fluvio-marine Series.

Of the fluvio-marine strata of the Isle of Wight, the *Bembridge* series is by far the most constant in lithological characters. The lower part is calcareous (marine and freshwater). The upper part (largest) consists of alternations of marls and laminated clays.

By far the larger portion of the Tertiary surface of the Isle of Wight is occupied by the beds of the Bembridge series, which overlies the Headon Hill group. Stratigraphically, or in a scientific point of view, they possess high interest, being *representatives of extensive continental formations*, through which we are enabled to correlate or at least throw considerable light on the classification of foreign Tertiary strata.

Through these Bembridge strata we are also made acquainted with and acquire much information respecting the terrestrial fauna of our own area during the later portion of the Eocene epoch.

Palæontologically, the Upper Bembridge marls are characterised by the abundance of *Melania turritissima*. These marls are finely shown in Whitecliff Bay, on the shore at Hempstead, and at Thorness, containing *Cyrena pulchra*.

The upper beds of the second group are exposed in the clearest manner through fine sections at the same places, and also at, or near Brading harbour, below St. Helen's. Remains of *Trionyx*, or the fresh-water tortoise, large *Cerithia* (*C. variabile*), and *Cyrena pulchra* characterise these beds.

The third group, or the Bembridge oyster-beds, forms a narrow but constant band between the marls and the limestones. Marine conditions set in here, characterised by the abundance of *Ostrea vectensis*, *Nucula similis*, *Cytherea incrassata*, *Mytilus*, and *Cerithium*. These beds were long mistaken for the 'upper marine' or Middle Headon strata. At Whitecliff Bay and Brading harbour this group may be advantageously studied.

The fourth subdivision, or Bembridge limestone, includes those beds exhibited at Binsted, Cowes, Calbourn, and Sconce (but not the limestones of the Headon series). It is important to remember this when correlating the British Upper Eocene deposits with those of the Continent.

This remarkable limestone in *Whitecliff Bay* forms a conspicuous feature in the cliffs; it is also the marked feature at Bembridge ledge. When closely inspected it is found to be composed of a number of distinct beds or strata. In ascending order we readily recognise seven divisions, each characterised by freshwater mollusca and some few land plants.

Bed No. 1. Concretionary limestone containing the fresh-water plant *Chara tuberculata*, with *Lymnæa longiscata*.

„ 2. Greenish marly clay, *Lym. longiscata* and *Planorbis*.

„ 3. Compact creamy-yellow limestone, *Lym. longiscata* and *Planorbis oligyratus*.

„ 4. Pale marly limestone, compact in places, full of *Paludina globuloides*, *Lym. longiscata*, *Hydrobia*, and *Cyclostoma mumia*.

„ 5. Greenish-white limestone, concretionary and fossiliferous, containing *Lym. longiscata*, *Planorbis discus*, *P. rotundatus*, *P. Sowerbyii*, *P. obtusus*, *Helix occlusa*, *Helix labryrinthica*.

„ 6. Crumbly white marl, with globular concretions, *Chara tuberculata*, *Planorbis obtusus*.

„ 7. A similar bed to 6, with *Planorbis discus*. The whole about 25 feet thick.

The strata along the coast and sections are in many places beautifully shown, and present peculiarities not elsewhere seen in the island.

Recent Classifications of the Upper Eocenes.

Professor Judd, in a paper communicated to the Geological Society in May, 1880, on the Oligocene strata of the Hampshire basin, having reference to the beds at Headon Hill and Colwell Bay, in the Isle of Wight, endeavoured to show that the Colwell Bay marine beds are not, as has been hitherto supposed, the equivalents of those of Headon Hill and Hordwell Cliff, but that they occupy a distinct and much higher horizon in the Eocene series. Assuming this to be the case, a new classification and nomenclature for the Upper Eocene series of Britain was proposed by the author.[1]

Professor Judd traced the history of previous opinion upon the succession of the Tertiary strata down to the time of Professor Edward Forbes and the Geological Survey, with the subsequent labours of Mr. Bristow. Edward Forbes confirmed the previous determinations of Professor Prestwich in his elaborate researches in the Isle of Wight Tertiaries. Forbes's life, however, was not spared to enable him to complete his researches in this division of the British strata; his attention was chiefly confined to the four uppermost Eocene members, or the Hempstead, Bembridge, Osborne and St. Helen's, and the Headon beds. These divisions were accepted and worked upon as a basis by the Geological Survey. With regard to these strata, Forbes maintained, as almost all previous observers had done, that the beds at Colwell and Totland Bays are on the same horizon as those at the base of Headon Hill and at Hordwell Cliff.

Professor Judd's view has been questioned and refuted by Messrs. Tawney and Keeping, in an elaborate paper also read before the Geological Society in May, 1881,[2] and in a subsequent communication to the Cambridge Philosophical Society in the same year, 'On the Beds at Headon Hill and Colwell Bay in the Isle of Wight.'

The importance of a correct reading and classification of these Middle Eocene strata in the Isle of Wight, and their correlation with beds of the same age in France, Belgium, and Germany, cannot be overlooked or over-estimated, and often as it has been attempted, the papers by the two above-named authors have still greatly added to our knowledge of the stratigraphy of the Eocene series of the Isle of Wight. It is impossible to dispute the validity of their researches and value of their sections. The publication of Mr. Judd's paper disputing the correctness of Forbes's work and that of the Geological Survey, and the proposal of a fresh classification, drew immediate attention to the labours of the older authors, but especially that by the Geological Survey—which was answerable for the latest, indeed the only known extended and complete analysis of the Upper Eocene strata of the Isle of Wight.

We owe a debt of gratitude to the late Mr. F. Edwards and Mr. S. V. Wood, for their valuable additions to our knowledge of the palæontology of the fauna of the fluvio-marine beds of the Hampshire basin. Since the publication of Professor Forbes's memoir upon the Isle of Wight, the molluscan fauna alone is at least three times as great as noticed by him, and since that time the remarkable fauna of Brockenhurst in the New Forest, discovered by Mr. Edwards, has been carefully studied by Von Könen for the mollusca, and Professor Duncan for the corals. These naturalists have shown the agreement of this fauna with that of the Lower Oligocene in North Germany. This Brockenhurst fauna is also identical with certain strata at the base of the Middle Headon beds at Whitecliff Bay, in the Isle of Wight.

Professor Judd in his paper describes the stratigraphical position of the Colwell Bay and Headon Hill beds, and their relation to each other, pointing out what he believed to have been an error on Forbes's part, relative to the correlation of the 'Venus bed' at the two places, in what is really a continuous section: Edward Forbes and the Geological Survey having carefully and correctly determined that *only one set of marine* strata occurred between the two brackish or estuarine and freshwater series. This fact has been again most carefully worked out by Messrs. Tawney and Keeping, leaving no doubt as to the interpretation and accuracy of the work of Forbes and the Survey, and establishing upon a firmer basis the continuity

[1] *Quarterly Journal of the Geological Society*, vol. xxxvi. p. 137.
[2] *Ibid.* vol. xxxvii. p. 85.

and equivalency of the Colwell Bay and Headon Hill marine series, through the 'Venus bed,' all being stratigraphically and palæontologically the same. Professor Judd insists upon 250 feet of strata intervening between the Bembridge limestone and the marine band of Headon Hill, but Forbes and the Geological Survey in their section show less than one-half of that thickness. Recent research confirms this view. At pp. 148–150, the author also endeavours to show that the palæontological evidence is in accordance with, and as complete as the stratigraphical. This of course is based upon the belief that both are read or interpreted rightly. The comparison is between the collective fauna of Whitecliff, Colwell Bay, and Brockenhurst on the one hand, and Headon Hill and Hordwell on the other hand; but Messrs. Keeping and Tawney have shown the illogical nature of conclusions drawn from such an admixture of beds. Each bed should be compared separately.

Professor Judd (on pp. 150-164) correlates the British fluvio-marine strata with that of the Continent, adding at p. 153 of this paper a list of his so-called Brockenhurst species from Whitecliff Bay, Colwell Bay, Brockenhurst, and Lyndhurst, with those species common to the Barton beds below and Hempstead series above. This so-called Brockenhurst, but really Middle Headon fauna, numbers 84 genera, and 187 species (65 of which are manuscript names). Four of the 13 corals of the Brockenhurst beds also occur in the Oligocene strata of North Germany. This conclusion was arrived at by Professor Duncan, independently of the work of Von Könen upon the mollusca in the same beds.[1] The author also prepared a list of the Hempstead or so-called Middle Oligocene fauna, in which no less than 40 genera and 101 species are named; 40 of these are manuscript names, by Mr. F. Edwards, thus reducing the described fauna to 61 species. The subdivision and nomenclature of the series is next given, and the author proposed to extend the 'name of the Headon series, so as to embrace all the beds between the Barton and the Brockenhurst series, and to call all those strata said to belong to the zone of *Cerithium concavum* the Headon group,' doing away with the smaller subdivision of Lower, Middle, and Upper. To all the beds between the Brockenhurst and Hempstead series Mr. Judd would apply the name Bembridge group; including the series both above and below the 'Bembridge series of Edward Forbes, and also beds referred by him to the base of the Hempstead, the Osborne and St. Helen's, and to the Upper Headon.' Such a proposal labours under the error of altogether failing to recognise the position which the Brockenhurst fauna occupies in this interesting series. Professor Judd in fact places the Brockenhurst beds not only above the Middle Headon, but above the Upper Headon and Osborne beds of Headon Hill. It occupies, however, in fact, a place at the base of the Middle Headon, as is well seen at Whitecliff Bay, and at Brockenhurst itself.

This change in the nomenclature and classification has not met with approbation, and is strongly opposed by Messrs. Tawney and Keeping in their exhaustive paper, and by Mr. Lucas in his communication to the 'Geological Magazine.'[2] Messrs. Keeping and Tawney elaborately defend the labours and views of the Geological Survey, giving a mass of evidence, both as to the order of the strata and the distribution of life-forms, clearly showing that the relations of the whole group can be determined by examination of the continuity of the Colwell Bay and Headon Hill beds, and that the brackish-marine beds of Colwell Bay correspond with the brackish-marine beds of Headon Hill in every essential particular, being, in fact, one continuous and unbroken sequence, as laid down by the Geological Survey; this the authors have again clearly demonstrated in the text of their Memoir, and laid down in their clear and continuous section from Cliff End or Lynchen Chine to near Alum Bay Chine, and synthetically proved in their vertical sections.

The following general and condensed description or analysis of the Headon series of Colwell Bay and Headon Hill, as given by Messrs. Tawney and Keeping, will aid those wishing to examine the section, prior to reading or possessing themselves of the original paper in the 'Quarterly Journal of the Geological Society,' vol. xxxvii., or that of Professor Judd, *loc. cit.*, Note 1.

[1] A. von Könen on 'The Correlation of the Oligocene Deposits of Belgium, Northern Germany, and the South of England,' *Quarterly Journal of the Geological Society*, vol. xx. p. 97.

[2] *Geological Magazine*, decade ii. vol. ix. p. 97.

Vertical Section at the North-east Corner of Headon Hill.—One hundred and ten feet of strata occur from the top of the Bembridge limestone to the top of the Great Limestone (Upper Headon). The Brockenhurst series does not exist here. Not a single marine fossil occurs in that interval. Nor is there any bed having the least resemblance either lithologically or palæontologically to the Colwell Bay Venus bed.

The *Upper Headon* at Headon Hill measures 50 feet, and contains the thick Lymnæan limestone (27 feet). The united or combined thickness of the Osborne and Upper Headon beds (Geological Survey) is 119 feet, *i.e.* adopting the top of the *Cerithium ventricosum* bed as the boundary. The Osborne beds at Headon Hill are below the Bembridge limestone and extend up to it, *so there is no room* for a greater thickness of beds.

The *Middle Headon.*—The uppermost and lower portions of the Middle Headon are brackish-water beds abounding in *Cerithium ventricosum, C. pseudocinctum, C. concavum, Neritina concava,* and *Nematuræ.* The beds or series in Headon Hill richest in *Cytherea incrassata* (Venus bed proper), exhibit identically the same fossils as at Colwell Bay.

Below the oyster band in grey sandy clays is the *Venus bed,* extremely rich in marine fossils. *Cytherea, Mya, Mactra, Corbicula, Nucula, Trigonocœlia, Fusus, Cancellaria, Voluta, Vicarya,* and *Natica*; *Mya angustata* and *Cytherea incrassata* scattered throughout and abundant. The Middle Headon of Headon Hill is 32 feet thick. The Survey vertical section gives 35 feet for the same boundaries. The height of the Middle Headon above the sea-level at the north-east end is 72 feet, and not below the sea-level, as seems required on Professor Judd's theory.

Lower Headon.—The first bed is a Lymnæan limestone, and is the same well-known bed which forms the top of the Lower Headon in Warden Cliff. It is traceable to How Ledge, where it disappears below the sea, and clearly shows by its course that it is the How Ledge bed of Warden Cliff. Although this limestone is denuded from the top of the anticlinal curve between Weston and Widdick Chines, some of the lower beds are traceable the whole distance; accordingly we can join on the section in Headon Cliff to that in Warden Cliff. This gives a continuous section and series of beds from the lowest seen of the Lower Headon, through the Middle and Upper Headon of Colwell Bay to the Bembridge limestone both north and south. There is therefore only one marine (*Middle Headon*) series lying between two freshwater series, or 'the Lower and Upper Headon.' The Rev. O. Fisher has discovered the Venus bed in the Totland Bay brickyard, some short distance above and behind the top of the cliff, between the chines. This being the only part where it is missing from the cliff is proof of its continuity from Warden Cliff to the north-east corner of Headon Hill.

The authors describe in the most careful manner the Lower Headon beds of the cliffs between Weston and Widdick Chines, much of the space in which is hidden by the grass slopes, but the connection cannot be doubted.

The Lower Headon of Warden Cliff.—'The lowest beds of this series are seen below the Totland Bay Hotel at Weston Chine, and all are below the Venus bed. A remarkable feature in the lowest portion are five thin Lymnæan limestones, containing *chara* seeds. These five limestones at low water form five submarine ledges parallel to the great ledge at Warden cliff' (Warden ledge). Above these five beds and the sands containing *Potamomya* comes the concretionary calcareous sand rock which forms Warden Ledge. It crops out at the top of the cliff below the flagstaff of the coastguard station. Succeeding these is the Unio bed (*U. Solandri*) which is associated with *Melania turritissima.* The How Ledge limestone succeeds and forms the summit of the Lower Headon series. This limestone is denuded away in the centre of Totland Bay, where we have evidence and may infer the summit of the anticlinal to be near the old wooden pier. The thickness of the Lower Headon in Warden cliff is 72 feet, and from that to 87 feet before reaching the yellow sands of the Upper Bagshot.

The whole of the cliffs between Weston and Widdick Chines are occupied solely and throughout by Lower Headon beds, and the Colwell Bay marine bed extends all through Warden point and cliff, where it rests upon, or is supported by, the How

Ledge limestone. Between Warden Battery and Weston Chine the Colwell Bay marine bed (Middle Headon) is maintained in all its integrity.

Middle Headon of Colwell Bay.—'The Neritina bed at the south-west end of the Bay is well seen a little short of Colwell Chine. Above this comes the richest part of the "Venus bed"—the fossils in which (*Cytherea incrassata*) strew the tumbled clays and commingle with recent shells on the shore.' *Ostrea velata*, as at Headon Hill, is abundant above the part richest in Cytherea. This oyster occurs in vast abundance in the centre of the bay between Colwell and Bramble Chines, crowding out other fossils and forming a massive oyster bank about 20 feet thick. The Venus bed here is altered in character, and abundantly occurring with *Cytherea incrassata* are *Murex sexdentatus*, *Pisania labiata*, *Natica labellata*, *Nerita aperta*, *Cerithium variabile*, and *Ostrea velata*.'

Upper Headon of Colwell Bay.—The horizon of *Cyrena Wightii* is a marked feature here, associated with *Corbicula obovata*; *Cerithium trizonatum* also occupies one horizon just below the buff-coloured Lymnæa limestone forming a narrow band with green clays; *Serpu ü enuis* is equally characteristic, occurring at the same horizon both here and at Headon Hill, viz. in the Upper Potamomya clay just above the Lymnæan limestone.

Palæontological Evidence.

Having noticed the stratigraphical succession of the several divisions in the beds at Headon Hill and Colwell Bay, I now proceed to draw attention to the distribution of the fossils.

The authors of the paper have discussed the question as to whether the Colwell Bay has any more affinity with the Brockenhurst fauna, than has the Headon Hill bed; and they compare the fauna both of the Colwell Bay and Headon Hill marine beds. This they do by separating in tabular form the fauna of all the localities which are to be compared together. The splendid collection of Tertiary fossils belonging to the late Mr. F. Edwards, and now in the British Museum, has formed the basis of their comparison, while their own researches have added occurrences still more conclusive as to the correlation of species in the areas under examination and consideration. The authors obtained during their research in the Isle of Wight many species in the marine bed at Headon Hill which do not exist in the Edwards collection from that locality. 'The test as to the contemporaneity of the beds in question is not to be obtained from the rarer forms only, but from a comparison of the commoner and more characteristic species.' No less than fifty-eight species were obtained by the authors from the Middle Headon of two localities, Colwell Bay and Headon Hill, nineteen of which appeared in and came up from the Barton beds, and with seven exceptions all the fifty-eight forms came from both horizons.

It has been stated that the '*strata at Colwell Bay are of purely marine origin, while the so-called Middle Marine beds of Headon Hill and Hordwell Cliff are of totally different character*.' But Messrs. Tawney and Keeping obtained from the marine series at Colwell Bay the brackish-water genera *Cerithium*, *Cyrena*, *Hydrobia*, *Lymnæa*, *Paludina*, *Planorbis*, *Melania*, and *Melanopsis*, although said to be found only at Headon Hill. It has also been stated that certain species of Cerithium are confined to Headon Hill, and do not occur in Colwell Bay, and that through this discovery serious errors in our classification have been detected, as well as in the correlation of the strata under consideration.

The presence of *Cerithium concavum* in the Venus bed abundantly at Colwell Bay—and we may add from private information from Mr. Keeping that he has found it also at Whitecliff Bay in the same position—removes all doubt as to the non-occurrence of the zone in that locality. As has been stated, the species is not so common at Colwell Bay as at Headon Hill.

There is but one marine bed, and that is known only in the Middle Headon. The place of the Brockenhurst bed is at the lowest horizon in the Middle Headon, but it does not appear at Colwell Bay, or anywhere in the west end of the island, but only at Whitecliff.

Middle Headon of Whitecliff Bay.—It has been stated that the Colwell Bay bed is placed in the Brockenhurst, which is said to occupy a higher horizon than the Headon Hill and Hordwell marine bed. The true place of the Brockenhurst fauna in the Isle of Wight is confined *to one zone*, and that at the *base of* the Middle Headon series, and *only at* Whitecliff Bay or in the New Forest.

The Geological Survey do not mention by name the Brockenhurst bed in their vertical section [Sheet 25] of Whitecliff Bay, as its peculiar fauna had not been recognised at that time. It is easily identified, however, in their section as the basement bed of their Middle Headon, the whole of which is given as 90 feet thick.

Brockenhurst Zone at Whitecliff Bay.—At the time the Geological Survey section was made, this bed at Brockenhurst was unknown, and its fauna undescribed. Subsequent observers have recognised the Brockenhurst fauna in the lowest bed (2 feet thick) of the Middle Headon at Whitecliff Bay. 69 species are known here, and 104 occur at Brockenhurst.

Affinities of the Brockenhurst Fauna.—If we take the whole Brockenhurst fauna, including the eighteen corals (special to the zone) we obtain a total of 151 species, of which from 74 to 81 pass up from Barton.

Messrs. Tawney and Keeping supply a list of 53 species from the Brockenhurst zone obtained from the Whitley Ridge Railway Cutting, New Forest. 51 of these 53 forms have occurred in the 2-foot bed at Whitecliff Bay, 27 of which pass up from the Barton or Bracklesham beds.

The palæontological evidence therefore accords with the stratigraphical.

Relation of Colwell Marine to Brockenhurst Fauna.—Examination gives us 29 per cent. of Barton forms in the Colwell Bay bed. In the Brockenhurst bed the ratio was about 50 per cent., and in the Headon marine bed, 29 per cent. Examination also of the more characteristic Colwell and Headon marine fossils shows that these faunas are practically identical—and also shows that only certain Brockenhurst species occur at Colwell Bay, and not at Headon Hill. They are *Scalaria tessellata* and *Tellina affinis*, this latter a Barton form, while those occurring at Headon Hill and *not at* Colwell Bay are *Marginella æstuarina* and *Cardita paucicostata*; only 'two in each case, which amounts to perfect equality.' If we take into account those common to the Colwell and Headon marine beds, and not occurring at Brockenhurst, we find twenty-six species. It is therefore evident that the Brockenhurst fauna is not identical with that of the Colwell Bay bed, and not newer than that of Headon Hill.

Thus fossil as well as stratigraphical evidence shows that the Colwell Bay bed is identical with the Headon Middle Marine.

The same twofold proof demonstrates that the Brockenhurst bed, where present, lies at the base of the Middle *Marine* Headon beds, and immediately above the Lower Headon. This Brockenhurst bed is absent at Colwell Bay and Headon Hill, but occurs at Whitecliff Bay, Brockenhurst, and Lyndhurst.

The proposal by Professor Judd to extend the name of the Headon series so as to include all the beds between the Barton and Brockenhurst series, and call them the 'Headon Group,' would cause great inconvenience. The term Middle Headon, based as it is on the classical work of Edward Forbes, is clear and definite. Again, it would entail the abandonment of the names Upper and Lower Headon also; and the non-occurrence of the Brockenhurst series, or its representative, in Colwell Bay admits of no recognition on the west side of the island, and therefore the classification would be based upon a defective appreciation of the beds.

Von Könen, in 1864, justly correlates the fauna, and since then, in 1866, the coral fauna has been described by Dr. Duncan.

Messrs. Tawney and Keeping, in their paper on the beds at Headon Hill and Colwell Bay in the Isle of Wight, uphold the work done by the Geological Survey, maintaining the correctness and integrity of the two Survey Memoirs, and the horizontal and vertical sections of the Tertiary beds of the Isle of Wight. Professor Judd differs from the identifications and stated succession of the beds in Totland and Colwell Bays. He introduces two new series at Headon Hill, a marine

and a freshwater (?) in addition to those which have been universally accepted for the last twenty-five years.[1]

The sections prepared by Professor Judd also differ very considerably from that of the Geological Survey, or those lately prepared by Messrs. Keeping and Tawney, during their late examination of the beds under notice. These are the marine series known as the *Middle Headon* or *Middle Marine*. Prof. Judd places them at the sea-level near Widdick Chine. Consequently, between the top of the marine bed and that of the Bembridge limestone, there would be, on Prof. Judd's theory, 250 feet of beds, such being the altitude of the cottage on the Warren which marks the summit of the Bembridge limestone. This thickness must, however, be reduced by 100 or 105 feet, which is the altitude of the top of the Middle Headon at this point. This 105 feet of beds, or *another* freshwater and *another* marine, have no existence; they can only be accounted for by counting the Lower and Middle Headon twice over. Now the only marine beds are those of the Middle Headon, enclosed between the altitudes of 70 feet above the sea-level; the others are all freshwater.

The point wherein Professor Judd's section differs from the Survey and that of the authors, arises from the belief that a second marine series, termed the 'Brockenhurst series,' with another freshwater below, in all 105 feet, is intercalated above the Upper Headon—these two believed new formations having that portion of the section allotted to them which is occupied by the freshwater Osborne marls and part of the Upper Headon. It must be remembered that there is no positive evidence of the existence of this second marine (*Brockenhurst*) series at the spot where the Geological Survey places the Osborne marls. Careful examination fails to reveal these said-to-be additional beds. It is clear, therefore, that no bed having the peculiar fauna of the Brockenhurst bed occurs at the west end of the island; its place too, if found, would be at the base of the Middle Headon and not above the Upper, where it has been wrongly assigned. Messrs. Keeping and Tawney, in their paper, object to the correlation of the Brockenhurst with the Colwell Bay bed—which is identical with the marine (Middle Headon) bed of Headon Hill. Thus the 105 feet of strata have no existence.

The Middle Headon, which is denuded away from the top of the cliffs in the centre of Totland Bay between Weston and Widdick Chines, has been discovered in the Totland Bay brickyard, which lies a little inland of this portion of the cliff, thus conclusively showing that this bed was continuous above the top of the cliff, consequently linking the Warden Cliff exposure to that of Headon Hill. They are visibly and absolutely continuous with those of Colwell Bay.

Palæontological Evidence.—The equivalency of the Colwell Bay and Brockenhurst beds is a point to be definitely settled. Most careful lists of fossils have been prepared from collections made both from the Middle Headon at Colwell Bay and Headon Hill. We find that out of fifty-seven species at Colwell Bay, fifty-three occur in the Middle Marine of Headon Hill, or 93 per cent. This clearly proves the identity of the horizon in the two localities.

The well-known shells *Cerithium concavum* and *C. ventricosum* occur both in Colwell Bay and Headon Hill, and on the same horizons. *C. concavum* appears to have a less restricted range at Headon Hill than *C. ventricosum*, occurring abundantly there through the greater part of the Middle Headon series. It has also been found in the 'Venus bed' of Colwell Bay. Thus both stratigraphical and palæontological evidence are in harmony. All evidence tends clearly and conclusively to show that there is *only one marine series* in this section, viz. the Middle Headon of Edward Forbes, which is interstratified between the freshwater Lower and freshwater Upper Headon; while there is no evidence of the Brockenhurst bed occurring anywhere in the west of the island.

Whitecliff Bay and the New Forest.—The Brockenhurst bed was recognised at Whitecliff Bay, by the Rev. O. Fisher, in 1864, where it occurs in the lowest two feet of the Middle Headon series. No less than 70 species have been collected here out of 104 known at Brockenhurst. Many species are peculiar to it, but all are identical with those of the well-known section in the railway-cutting near

[1] *Quarterly Journal of the Geological Society*, vol. xxxvi. p. 137.

Brockenhurst. Many species are confined to this horizon and do not pass up into the 'Venus bed.' Thus the Brockenhurst fauna at Whitecliff Bay numbers 70 species, at Brockenhurst 104, and of these only eighteen occur in the Middle Marine beds of Colwell Bay, or are common to Whitecliff Bay and the type locality. Eighty-three Barton or Bracklesham species pass up, twenty-five to the Middle Marine of Colwell Bay, and thirty-six to the Brockenhurst bed of Whitecliff Bay, or these two localities yield the above number of Bartonian forms. To still further illustrate the value of the Middle Headon series of the Isle of Wight and elsewhere, I may mention certain characteristic fossils that occur in several zones. The '*Venus* bed' of the Geological Survey is about thirty feet thick at Colwell Bay, Headon Hill, and Whitecliff Bay, and contains the following well-marked shells, *Murex sexdentatus*, *Melania fasciata*, *Cerithium duplex*, *C. ventricosum*, *C. concavum*, and *Nerita aperta*. Shells characteristic of the Brockenhurst bed and confined to it are *Voluta suturalis*, *Leiostoma ovatum*, *Pecten bellicostatus*, *Modiola nysti*, *Cyprina nysti*, and *Cytherea solandri*, var. *attenuata*. In the Roydon zone occurs *Voluta geminata*, and nowhere else in England. *Pleurotoma transversaria*, *P. subdenticulata*, *Cardita deltoidea*, and *Protocardium hantoniense* are in both the Roydon and Brockenhurst zones, but not known in the Venus bed. Certain species range through the Middle Headon series and occur nowhere else. These are *Pisania labiata*, *Pleurotoma headonensis*, *Cancellaria muricata*, *C. elongata*, *Leda propinqua*, *Cytherea suborbicularis*, *Psammobia æstuarina*, and *Corbicula obovata*. The Brockenhurst zone is restricted to the lower 2 feet of the Middle Headon, and it lies immediately on the eroded surface of the Lower Headon. An error certainly has been committed in the New Forest section, in assigning the place of the Brockenhurst series above the Middle Marine or Middle Headon. This is at variance with facts at Brockenhurst and Whitecliff Bay, and this misapprehension as to the stratigraphical position of the Brockenhurst bed refutes the theory as to the occurrence of this bed high up in Headon Hill. It is not in existence there.

With reference to the affinities of the Brockenhurst fauna, it has been stated that 'nearly one-third of the Hordwell and Headon Hill marine shells are Barton forms, and not more than one-fifth of those occurring at Brockenhurst, Colwell Bay, and Whitecliff Bay, are found at Barton.' We should not expect the *Venus bed* or *Middle Marine* would have more Barton species than the Brockenhurst bed, seeing that the former occupies a higher zone in the Middle Headon series. The percentage of Barton forms, according to Mr. Tawney, in the Whitley Ridge bed, is 42 per cent.; a lower proportion than at Whitecliff Bay, arising from the number of corals being special to the Whitley locality. At Whitecliff Bay the Barton group has 52 per cent., and the proportion of Barton forms from all the Brockenhurst localities, including the Roydon zone, is 48 per cent., and the percentage of the Barton forms in the Middle Headon of Headon Hill is found to be 29 per cent.; the conclusion therefore from fossil evidence is that the Headon Hill marine bed is later in age, and higher stratigraphically than the Brockenhurst bed, the proportion of Barton forms in the latter being nearly 50 per cent., and not one-fifth, as stated. The result is in strict accordance with their stratigraphical positions. It is equally important to test by fossil evidence whether the Colwell Bay Venus bed (Middle Headon) is more nearly related to the Brockenhurst than is the Headon Hill bed. In Colwell Bay the observed Barton forms are 29 per cent. in common, and the same percentage in the Headon Hill bed, while in the Brockenhurst bed they were 48 per cent. To test still more the proof from palæontological evidence, it is stated, on the same authorities, that there are only two species in each case common to either Colwell Bay, or Headon Hill and Brockenhurst, and not occurring at Barton; while there are twenty-six species common to Colwell Bay and Headon Hill, and not occurring at Brockenhurst. It is clear, therefore, from all fossil and physical or stratigraphical evidence, that the position of the Brockenhurst bed has been misconceived; and it would be fatal to re-name the whole series of strata hitherto so well known and well determined as the Middle Marine or Middle Headon, of the Isle of Wight, and call it the 'Brockenhurst series.' The classification and nomenclature of the Geological Survey must therefore be restored and maintained, all recent examination

having strengthened the previous labours of Forbes and Bristow, and the later researches of Messrs. Tawney and Keeping have still more firmly established the succession and correlation of the Middle Headon series of the island, and affording a basis for further research and analysis for the 'Anglo-Parisian or Hampshire Tertiary Basin.'

Mr. Tawney prepared an important paper upon the *Upper Bagshot Sands of Hordwell Cliff*, which was read before the Cambridge Philosophical Society and published in their Proceedings. The object of the communication was to discuss the affinities of the Bagshot series with a view to their classification, and also to endeavour to show their correlation and equivalents in the Paris basin. 'All observers are agreed as to the actual position of the sands being below the freshwater Lower Headon. Edward Forbes and the Geological Survey distinctly ally it to the Marine Bagshot beds. They place it in the Middle Eocene Bagshot series, terming it Upper Bagshot (instead of Headon Hill Sands). Forbes noticed the fact of its containing Barton species at Whitecliff Bay. This shows its affinity to Barton beds. Dumont favoured a similar classification in his essay, and in his table the Headon Hill sands are grouped with the Barton clay as being respectively equivalent to the upper and lower divisions of the *Belgian Laekenian*, while the Headon Hill limestones and marls are placed in the *Tongrien*. Lately these views have been questioned by the author of the 'Oligocene Strata of the Hampshire Basin,' in the 'Quarterly Journal of the Geological Society,' vol. xxxvi., who regards these beds as constituting the lowest member of the Headon group, stress being laid upon the occurrence of *Cerithium concavum* as a test. The author also places the whole of the Upper Bagshot sands and the Lower and Middle Headon beds as the equivalents of the Mortefontaine sands, placing them above the St. Ouen limestone; these St. Ouen beds representing perhaps the Osborne, and all three Headon divisions, which come above the Mortefontaine beds. *Cerithium concavum* is said to occur both in the Bagshot and Headon series. Careful research and examination shows that the shell in question is Lamarck's *C. pleurotomoides* in the one case, and not *C. concavum*, which species has evidently been confounded with the Lamarckean shell. Examination of equivalent beds in France by Mr. Tawney, and the researches of Professor Hebert and M. Munier-Chalmas clearly show that the Mortefontaine sands do not contain *Cerithium concavum*, the shell so common on that horizon being *C. pleurotomoides* Lamk. Comparison of the Headon shell with those brought from near Mortefontaine shows that the Long Mead End species agrees with the French form. It would appear that there is much greater parallelism between the French and English series than we have hitherto expected. The Mortefontaine sands are the upper part of the Sables de Beauchamp, representing our Barton beds; above this comes the Calcaire de St. Ouen, chiefly of freshwater origin. Connected with the St. Ouen limestone are sands and marls, containing at the top and bottom *Cerithium concavum* abundantly.

The St. Ouen period, therefore, without doubt represents our Headon series. 'In our Hampshire basin the freshwater and marine condition in the Headon series are not in the same order as in the St. Ouen beds.' 'The marine facies in Hampshire, with *C. concavum*, comes between the freshwater Lower and Upper Headon deposits, near Montjavoult; the bulk of the freshwater limestones is in the centre or between two deposits with this *Cerithium concavum*.' 'In the Paris basin, therefore, the zone of *C. concavum* is not connected with the zone of *C. pleurotomoides*, but comes immediately above it.' Thus *C. concavum* characterises the Middle Headon of Colwell Bay and Hordwell, while *C. pleurotomoides* is found only in the Upper Bagshot of Long Mead End. That the Long Mead End sands and those of Mortefontaine are equivalents few can doubt. Both succeed or constitute the uppermost portion of the Barton beds, and 25 per cent. of the fossils are in common. These affinities show that the term Upper Bagshot sands is the most appropriate, and expresses the relationship of these sands, since the Barton and Bracklesham beds together are usually considered as the equivalents of the Middle Bagshots. The author believes, therefore, that it would be wrong to reject Edward Forbes's name of 'Upper Bagshot' for the Long Mead End sands, and accept in place of it the older term of Headon Hill sands.

Mr. A. H. S. Lucas, M.A., in his concise but valuable paper 'On the Headon Beds of the Western Extremity of the Isle of Wight,'[1] correctly states, upon referring to the recent 'answer to the present questioning of the hitherto accepted correlations of the beds of the Lower fluvio-marine Tertiaries of the Isle of Wight and South Hants, that it is obviously impossible for foreign geologists to institute useful comparisons between British and foreign subdivisions so long as we in England are quite at variance on the stratigraphical and palæontological facts of the beds in question.[2]

'The general relation of the whole group can only be satisfactorily determined after the primary question of the continuity or discontinuity of the Colwell Bay and Headon Hill beds is settled. At present there are two very definite, yet different views, having a perfectly distinct issue; first, that the brackish-marine beds of Colwell Bay correspond with the brackish-marine beds of Headon Hill which have been seen; or, secondly, that they correspond to some higher marine beds which have not been seen.' Both these views and arguments are now fairly before those competent to judge. In 1880, however, Professor Judd, in his paper 'On the Oligocene Strata of the Hampshire Basin,'[3] questioned and denied the succession as determined by Forbes and the Survey; this paper dealt with strata or higher marine beds stated above by Mr. Lucas as 'not having been seen.' On the other hand, in 1881, Messrs. Tawney and Keeping brought to bear upon the question a mass of evidence in support of the work of Edward Forbes and the Survey[4] showing conclusively the identity and continuity of the Colwell Bay and Headon Hill fluvio-marine beds. Still more recently, however, Professor Blake [5] has 'advanced an entirely new correlation, adducing stratigraphical evidence in its favour.' His observations do not agree in certain cases either with those of Professor Judd or Messrs. Tawney and Keeping. It is hoped, however, by or through evidence at the present meeting, that the question of the succession will be finally determined. Mr. Lucas does not attempt any solution as to the relation of these beds at Colwell Bay and Headon Hill to the deposits exposed at Hordwell, Brockenhurst, or Whitecliff Bay; they do not concern the succession. But the standard or synthetic sections at different localities, like those prepared by Messrs. Tawney and Keeping, have tended to clear up the succession, fully testing the continuity of the beds under dispute under their several aspects along the plane of deposition. This independent mode fully bears out the exact work of the Survey, showing differences in degree as regards accumulation, yet continuity as regards succession. Mr. Lucas gives measured sections of the freshwater beds, and the brackish marine series (p. 99 *loc. cit.*), which confirm the work of the above authors.

The Headon beds were long ago 'measured by Dr. Wright, lately by the authors just quoted, and the Osborne series by Edward Forbes, and the main divisions are so conspicuous that there can be no doubt about the succession.' A third paper upon the Fluvio-marine Beds of the Isle of Wight was read before the Geologists' Association, in June 1881, under the title, 'On a Continuous Section of Oligocene Strata from Colwell Bay to Headon Hill,'[6] by Prof. J. F. Blake, M.A., F.G.S. The author contends for a difference between the faunæ of the Colwell Bay beds and those of Hesdon Hill, and states that the 'fauna of the so-called Oligocene group is chiefly to be found in the "Venus bed" of Colwell Bay; but the assumed *other* "Venus bed" at Headon Hill contains rather the fauna of the uppermost Eocene, or zone of *Cerithium concavum*.' The question, however, turns upon the identity of the two so-called Venus beds. In other words, the Colwell Bay 'Venus bed' is said by the author to have one fauna, and the Headon Hill 'Venus bed'

[1] *Geological Magazine*, n.s. decade ii. vol. ix. p. 97.

[2] A concise and important paper on 'The Classification of the Tertiary Deposits,' by Professor Judd, appeared in the *Popular Science Review* for 1880, accompanied by a table showing the correlation of the Lower Tertiary strata of Western Europe. The Headon and Brockenhurst beds are placed under the Lower Oligocene, and the Bembridge and Hempstead series under the Middle Oligocene.

[3] *Quarterly Journal of the Geological Society*, vol. xxxvi. p. 137 etc.

[4] *Ibid.* vol. xxxvii. p. 85.

[5] *Proceedings of the Geological Association*, vol. vii.

[6] *Ibid.* vol. vii.

another. This determination I hold to be untenable, all fossil and physical evidence being to the contrary, and show that they are one and the same bed. On both sides of Bramble Chine the 'Venus bed' is fully developed. Mr. Blake calls it the 'Oyster bed.' Below these come thin bands of stratified marl, with abundance of *Cerithea* and *Cyrena* (not Cyclas, as stated). The Widdick Chine sands can be no other than the Headon Hill sands, and not the Upper Bagshots. The altitude of these sands above the sea Mr. Blake estimated at 100 feet; this is certainly too great an elevation, 70 feet being the received measurement by independent observers. Such difference, if it existed, would alter the reading and sequence of succeeding and higher beds in the section. The author seems to have omitted the *Trigonocœlia* and *Neritina* bed immediately above the How Ledge limestone and below the thick oyster band. These correspond with the Warden Cliff section, and determine continuity of deposition, or are a confirmation of the identity of the beds. This is a crucial point in the continuity and equivalency of the marine series in Totland and Colwell Bays. The *Trigonocœlia* bed here is on the same horizon as in Warden Cliff and Colwell Bay, associated with *Cerithium pseudocinctum*, *Melanopsis fusiformis*, *Natica labellata*, &c. The lower or *Neritina concava* bed, with *Melanopsis fusiformis* and *Corbicula ovata*, occurs also in the same position near the base of the series at Warden Cliff and Colwell Bay. 'This can only be explained by admitting that the Marine series in Totland Bay and Colwell Bay are identical.' The occurrence of '*Cerithium ventricosum* at the top, and the *neritina* [*N. concava*] and *Trigonocœlia* [*T. deltoidea*] at the base—identical in physical and fossil characters, are strong presumptive proof of this.' It is extremely doubtful if *Cerithium margaritaceum*, mentioned on page 6 of Mr. Blake's paper, occurs in the Colwell Bay section, or in the western area of the Isle of Wight—the *Cerithium cinctum* is really *C. pseudocinctum*, and *Cyclas obovata* should be *Cyrena obovata*. The genus *Cyclas* does not occur. In correlation these are important items, especially with a continental fauna. It will also be found that the oyster beds do not rest immediately on the How Ledge limestone as asserted—the *Trigonocœlia* and *Neritina* beds intervene, and, as at Colwell Bay, determine or prove the succession and identity of the series. At pp. 156–7 Mr. Blake remarks upon the similarity of the succession of the Colwell Bay beds with those of Headon Hill, and is 'tempted to come to the conclusion' that the two 'Venus beds are identical;' [they have always been so believed and recognised]; he at the same time states that 'it would be absurd to argue that they are identical because they contain similar common fossils,' when it has been 'determined by Professor Judd that the faunas are remarkably distinct.' We have no other method whereby to determine the age and synchronism of deposits except through organic remains, and the faunæ of the 'Venus beds' at both localities are to me identical, and Professor Blake depends upon fossil evidence all through his paper, yet evidently he has not carefully examined the more complete fauna of the 'Venus bed' at both localities. In another paragraph, on page 157, the author states the proposition 'that the Colwell Bay "Venus bed" is not certainly identical with that at Headon Hill, but may occupy a higher horizon.' Mr. Blake suggests that the Headon Hill bed corresponds with the series intervening between the Colwell Bay bed and the How Ledge limestone; and that the Colwell Bay bed corresponds with the slightly fossiliferous sands immediately below the Headon Hill limestone. This position or suggestion certainly cannot be received. In this case the so-called two 'Venus beds' would be superposed on each other, and nothing to separate them. The sands referred to are those at the base of the Upper Headon series, and are freshwater, for they contain *Unio*. Again, Professor Blake's suggestion would thus place the Colwell Bay 'Venus bed' below the Great Limestone, whereas Professor Judd in his paper would place it above.

The author does not find any equivalents of the Colwell Bay oyster beds above the Headon Hill limestone at Headon Hill; indeed that would be impossible, for they are indisputably the Osborne marls of Professor Forbes, and capped by the Bembridge limestone.

As regards the terms Eocene and Oligocene, and their relation to each other, and the correlation of British strata and fossils with those of Germany, &c., it is

far too intricate a question to be passed over, although without doubt the fluvio-marine strata of the Hampshire basin will ere long receive critical supervision with reference to similar deposits on the Continent. So far back as December 1863, Herr Adolf Von Könen read his paper on the correlation of the Oligocene deposits of Belgium, North Germany, and the South of England, and endeavoured to show that in Britain we had an assemblage of fossils in our so-called Middle Eocene at Brockenhurst, Lyndhurst, and Roydon in the New Forest, that could be stratigraphically correlated with beds of the same age termed Oligocene in Northern Germany. The author believed that these Brockenhurst beds were of the same age as the Middle Headon beds of Colwell Bay and Whitecliff Bay. This view has led to much controversy, arising from the fact that no Brockenhurst species occur in Colwell Bay. The rich cabinet of Mr. F. Edwards then afforded Von Könen every facility for the comparison and determination of the species occurring common to Britain and Germany. Beyrich established the name Oligocene for the fossils of this age in Germany. The Lower Oligocene is well-developed, with a true marine fauna, in Belgium near Tongres (N. of Liège) and in the N. of Germany between Magdeburg, Bernberg, Egeln, and Helmstadt (near Brunswick). This Lower Oligocene contains 700 species of mollusca besides other groups. The most characteristic of these the author asserts are found at Brockenhurst, and in Mr. Edwards's cabinet fifty-six species occur, twenty-one of which are Barton clay forms, and forty-three of the fifty-six species occur in the Lower Oligocene of Germany.

The following Papers and Report were read:—

1. *Notes relating to some of the Drift Phenomena of Hampshire*: 1. *Boulders, Hayling Island*; 2. *Chert Débris in the Hampshire Gravel*; 3. *Elephant Bed, Freshwater Gate. By* Professor PRESTWICH, *M.A., F.R.S., F.G.S.*

In this paper the author draws attention to a few points which have either escaped notice or on which he would put a different construction. 1. The remarkable boulders of crystalline and other old rocks of Pagham were noticed long ago by Mr. Dixon and Mr. Godwin-Austen; and Mr. Codrington has more recently described similar boulders in the gravel of Portsea Island. Those of Hayling Island have not yet been noticed; nevertheless they are very numerous. The author describes two of *granite* and three of *sandstone* of large size on the shore near the railway station, and states that he counted thirty smaller ones in a mile to the westward of the station. The greater number, however, of those on the shore facing South Hayling village seem to have been collected to form rockwork in the Grotto grounds and in the grounds of Westfield House. Amongst them are boulders of *granite, syenite, porphyry, slate*, and *sandstone*. They are found scattered in lesser numbers all over the island, embedded in the flint gravel and loam which overlies the London clay. Mr. Godwin-Austen considered that the Sussex boulders might be derived from an old coast now submerged in the area of the British Channel, but the author sees reason to believe that they are more probably derived from the coast of Devon and Cornwall. A large fragment of silicified Portland wood has been described by the Rev. O. Fisher from Pagham, and the author saw in Hayling Island a piece above two feet in length of well-characterised Portland wood. The granites and other rocks, though not yet determined, seem to resemble West of England rocks, and he saw none of the characteristic granite of Cherbourg amongst the boulders. Further, the author found at Stubbington Cliff and Hill Head numerous quartzite pebbles similar to those of the Budleigh conglomerate. He concludes therefore that the boulders were carried here by ice at the time of the old Raised Beach of Brighton, Portland, and the Devon coast, and that their absence in the intermediate area is due to the destruction of the beach and the wear back of the old coast line, except at a few spots where, with remnants of the beach, the boulders have been preserved.

2. Amongst the elements of the flint gravel of the Hampshire (inland) area, Mr. Codrington notices the abundant tertiary débris, and a few old rock and

quartz pebbles, but the occurrence of *Greensand chert* and *ragstone* does not appear to have been yet noticed by any writer on the subject. As this constitutes a very essential point in the consideration of the origin of the drift and other questions, the author wishes to draw attention to its constant presence in all the flint gravels from the coast to the extreme northern boundary of the tertiary basin, not only in the low-levels and valleys, but also in the higher level gravels of the highest hills, of chert and ragstone which so far from being rare are often present in the remarkably large proportion of 5 to 10 per cent.

3. The drift at Freshwater Gate has been divided into lower and upper flint gravel and overlying brick earth; the upper gravel with *elephant* remains, and the brick earth with *pupa* and *succinea*. The author considers, however, that the drift constitutes only one mass irregularly bedded and irregularly intercalating; that it is in fact a series of lenticular and thinning-out masses rather than regular beds. In this respect as well as in its organic remains it resembles the drift and rubble bed overlying the Raised Beaches of Brighton, Sandgate, Portland, and the coast beyond, with which, therefore, the author correlates it. The author further shows that, as suggested by Mr. Codrington on other grounds, the land at the back of the Isle of Wight has been much encroached on by the sea, and he argues from the presence of chert from the Greensands, and of ironstone fragments apparently from the Wealden, that the valley at Freshwater Gate extended some distance further south and ended in hills, now removed, of Wealden and Greensand strata.

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2. *Notes on the Bure Valley Beds and the Westleton Beds.* *By* HORACE B. WOODWARD, *F.G.S.*

After referring to two papers read before the British Association at York in 1881 by Prof. Prestwich, the author stated his reasons for concluding that the pebble-gravels of the Bure Valley with *Tellina Balthica* (the *Bure Valley Beds* proper) were distinct from the shingle at Westleton (the *Westleton Beds* proper). In company with Mr. J. H. Blake, he had (in 1876) traced the latter beds from Westleton to Dunwich Cliff, where they occurred in the upper part of the so-called 'Middle Glacial' beds of Messrs. Wood and Harmer. These Westleton Beds, consisting largely of flint-shingle, have been traced from Westleton and Southwold to Halesworth and Haddiscoe. In the neighbourhood of Haddiscoe and Loddon, the author had found evidence to show that this shingle occurred above the Lower Glacial brick-earth (Contorted Drift), and hence that the Westleton Beds could not be of the age of the Bure Valley Beds, which occurred beneath this brick-earth, and (in his opinion) formed the upper portion of the Norwich Crag Series. For the same reason, the Mundesley Beds, which occurred beneath the Lower Glacial Drift on the Norfolk coast, could not be of the age of the Westleton Beds. Nor were the Mundesley and Bure Valley Beds of the same age. The former include the *Leda myalis* Bed of Mr. C. Reid, which occurs at the top of the Forest Bed Series; the latter are equivalent to the Weybourn Crag which occurs at the base of the Forest Bed Series. Hence the Bure Valley Beds were part of the Norwich Crag Series, and of Pliocene age; the Mundesley Beds belonged to the debateable group of 'Pre-Glacial' Beds; while the Westleton Beds were of Glacial age.

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3. *On the Sources of the Salt Supply of India.* By Professor V. BALL, *M.A.*, *F.R.S.*, *F.G.S.*

Although the general economic importance of the salt trade of India is widely recognised, the nett annual revenue derived from the salt tax amounting to 7,000,000*l.*, still the actual nature of the varied sources which contribute to the supply are perhaps not so well understood as might be expected.

These sources may most conveniently be ranged under the following headings:—

I. *Imports.*—Chiefly from the United Kingdom, but also from Arabia. Total per annum 300,000 tons.

II. *Sea-salt.*—Is prepared in pans on the sea-coast, either by solar or artificial evaporation.

III. *Lixiviation of Saline earths.*—The presence of various salts in the soil is attributable to a high degree of evaporation unaccompanied by subsoil drainage. Sterility over wide areas, where this is the case, has often resulted from irrigation.

IV. *Saline Springs and Wells.*—Very abundant in parts of Assam, Burma, and the Punjab, where, as is often the case in other countries, they occur in conjunction with petroleum springs.

V. *Lakes* with large drainage areas and no outlets. Principal of these situated in Rajputana. The present annual out-turn of the Sambhar Lake exceeds 100,000 tons.

VI. *Rock-salt.*—There are two deposits, both situated in the Punjab; though geographically speaking they occur near to one another, geologically they are widely separated, being of Silurian and Eocene ages respectively.

The author having given some details under each of the above headings, and mentioned the modes of occurrence of some other salts besides the sodium chloride, stated that more complete information on these subjects would be found in his 'Economic Geology of India.'

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4. *Preliminary Report on the Flora of the 'Halifax Hard Bed,' Lower Coal Measures.*—See Reports, p. 267.

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5. *On the Iron and Lead Measures of Tynehead, Alston. By* C. E. De Rance, *F.G.S. Assoc. Inst. C.E.*

The carboniferous limestone of this area is capable of division into a series of beds of limestones, separated by thick deposits of shale and sandstone, traversed by an intrusive sheet of basalt known as the Whin Sill. The section above that horizon consists only of 200 feet of limestones, while sandstones reach 350 feet, and shales 520 feet. Beneath the Whin Sill there are 900 feet of measures in which occur many important beds of limestone, one of which, the 'Melmerby Scar Limestone,' reaches a thickness of 124 feet. The chief lead measures occur in the Great Limestone (70 feet), the Scar Limestone (30 feet), and in the Tyne Bottom Limestone—the latter deriving its name from the South Tyne over which it flows for a considerable distance. Below this horizon but little has been done to explore the lead lodes, owing to the water-charged character of the strata beneath the river bed.

The veins are nearly in every case faults of small throw. Where the two 'cheeks' consist of limestone, the fissure forming the vein contains lead, when it intersects beds of sandstone it is filled with copper, and in both cases, when these are absent, the veins are filled with brown iron-ore, containing 30 to 45 per cent. of metallic iron. Should the proposed railway between Middleton in Teesdale and Alston be carried out, it will bring these valuable iron-ores into easy access of the Middlesboro' iron furnaces.

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6. *On the Geology of Cardigan Town. By* Walter Keeping, *M.A., F.G.S.*[1]

The pale felspathic grits and black slates of Newport Bay and Cardigan are of Middle Bala or Caradoc age—not Llandovery as hitherto supposed.

Above these come (2) rolling beds of pale-coloured, coarse, flaggy slates, and pale blue splintery slates, doubtless also of Bala age. Some rather darker shaly slates (3) with rabby shales and 'cone in cone' concretions next succeed, and then we meet with (4) a small compact set of pale felspathic grits of the same character as those at Cardigan. These also I regard as probably of Bala age

[1] *Geological Magazine*, 1882, p. 519.

(Upper Bala slate series). The overlying rather dark shaly slates (5), with some rab, presenting the gradual incoming of the Aberystwyth grits, are passage beds of Caradoc—Llandovery age.

The grits of Llangrannog are the same as those of Aberystwyth (Aberystwyth grits), and the overlying slates with worm-like markings are our 'Metalliferous slate series' which belong to the same great rock group.

There is no evidence of any stratigraphical break in the rock groups of South Cardiganshire from the Llandeilo to the Llandovery period inclusive, but the whole series appears perfectly continuous.

The Aberystwyth grits are less developed here than further north, this being near the line of their southerly disappearance by dying out.

Here then, as in North Wales (Dovey Valley), we find a considerable series of Upper Bala slates passing up into the Llandovery group. It has been proved elsewhere that the Cardiganshire rock group lies conformably under the Tarannon shales, and here we find its inferior limits equally ill-defined, gradually passing down into a great series of imperfect slate-rocks which belong to the Upper Bala group.

Thus we find no great physical break, but perfect continuity amongst the Silurian and Cambrian rocks of South Wales.

FRIDAY, AUGUST 25.

The following Papers and Reports were read:—

1. *On the Post-Miocene Deposits of the Bovey Basin, South Devon.* By W. Pengelly, *F.R.S.*, *F.G.S.*

The deposits of the Bovey Basin stretch in a south-easterly direction for about nine miles from the neighbourhood of the little town of Bovey Tracey to that of Kingskerswell. The river Teign flows through the area for about five miles, and its tributary, the Bovey, for about three miles. Investigations carried on in 1860–1 showed that, near the north-western end of the basin, the deposits consisted of three distinct groups, the lowermost being a group of lignites, clays, and sands; on which lay unconformably an accumulation termed 'Head,' consisting of clay and sand, with very numerous angular and subangular stones; on which again lay the uppermost group of clays and sands, with remains of the dwarf birch (*Betula nana*). The lignite group is admitted on all hands to be of Lower Miocene or Upper Eocene age; the *Betula nana* clays belong with equal certainty to early post-glacial times, when a flora now confined to Arctic and Alpine habitats flourished in South Devon; whilst the intermediate Head, necessarily of intermediate age, is believed by most observers to be of glacial age and origin.

Since 1861 a human figure carved in wood, potsherds, and a bronze spearhead, have been met with in various parts of the Head, all near the Teign, and below its ordinary level; whilst in 1881 a canoe, formed by hollowing out a large tree, and nine feet long, was found thirty feet below the surface; that is to say, it lay twenty feet deep in clay, over which was the Head, having a depth of ten feet. Its site was twenty feet above the level of the highest known flood-waters of the Bovey, the nearest river, and eighty feet above spring-tide highwater.

In speculating on the chronology of the 'finds,' the writer stated that there was historical proof that there had been no change of level within the area since the Norman Conquest, and if the *Fosse-way* be a Roman work, none since the Roman occupation. He was of opinion that the hypothesis of the rivers having, in times of flood, dislodged and redeposited portions of the Head, and incorporated comparatively modern objects, was sufficient to account for the presence of the wooden figure, the potsherds, and the spearhead; but that the canoe, from its great depth in the clay, in which stones had never been found, belonged to a different

category; that, in short, he saw no reason to doubt that the era of the canoe was prior to that of *Betula nana* in Devonshire; prior, also, to the accumulation of the Head; and that, *if the Head be of Glacial age*, the canoe belonged to at least Glacial times.

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2. *On the Origin of the Hœmatite Deposits in the Carboniferous Limestone.* *By* EDWARD WETHERED, *F.G.S.*, *F.C.S.*

The author contended that the so-called 'pockets' of hæmatite which occur in the Carboniferous Limestone were caverns and fissures into which the ore had been introduced by water agency. There were two or three signs which indicated an approach to a pocket of ore.

1. Joints appeared in the rock through which water percolated.
2. An ordinary cavern opened out, termed by the Welsh miners a 'locus,' the sides of which were coated with large crystals of carbonate of lime.
3. Traces of iron are found in the 'locus.'

The fact that the first indications of ore were cracks in the rock, down which water percolated, certainly pointed to the inference that by a similar percolation, the hæmatite has been brought into its present position. That it has been deposited by aqueous agency was clear from the crystalline character of some of the ore. Further, there was just what would be expected from water containing the carbonates of lime and iron in solution where not exposed to the atmosphere, namely, lime has been first deposited and subsequently hydrated peroxide of iron.

The next point considered was, from whence was the iron derived. The highly ferruginous character of the Carboniferous strata was well understood, and the fire-clays indicated that large quantities of iron had been rendered soluble by the deoxidizing influence of decaying vegetable matter, and removed by the percolation of water. But, as to whether it was this iron which had given rise to the Carboniferous Limestone hæmatite deposits was a matter for consideration. It was doubtful whether there would have been sufficient time for the fissures and caverns to have so far developed as to form receptacles for the coal-measure water charged with carbonate of iron. It must, however, be remembered that after the uplifting of the Palæozoic rocks there was a vast lapse of time during the denudation by the Triassic Sea, and that much of the limestone, not now overlain by the Coal Measures and Millstone-grit, was covered by those beds for a considerable time. Further, water percolating through the Coal Measures would become highly charged with carbonic acid, given off from vegetation undergoing transition into coal, and water, so charged, would not be so long in dissolving and eroding out caverns.

Mr. Etheridge had referred[1] the origin of the Carboniferous hæmatites, in the West of England, to the infilling of faults, fissures, etc., during the denudation by the Triassic Sea; but stated that "doubtless the percolation of water through overlying strata, highly charged with oxides of iron, had been a source and mode of accumulation." Though the author was disposed to consider it possible that some of the hæmatite may have been derived from the percolation of water through the Coal Measures and Millstone-grit, yet he agreed with Mr. Etheridge that the most probable source was from the Trias rocks; not, however, during the accumulation of the strata composing that formation, but by subsequent percolation of water after consolidation of the beds. This water, on arriving at the Carboniferous Limestone, would flow down the cracks, fissures, and joints, provided there were such, but a comparatively small portion would filter through the actual rock on account of its being but slightly pervious to water. The author considered that it was owing to this fact that we generally find hæmatite where the Magnesian Conglomerate rests upon the Carboniferous Limestone. The water being unable to penetrate the rock, would naturally find an outlet at the junction of the two formations, and the conditions would soon be arrived at when the deposition of the iron would take place.

[1] *Quart. Journ. Geol. Society*, 1870, ix. 185.

3. *Report on the Earthquake Phenomena of Japan.*—See Reports, p. 205.

4. *Report on the Conditions under which ordinary Sedimentary Materials may be converted into Metamorphic Rocks.*—See Reports, p. 239.

5. *On some Fossils of the Inferior Oolite. By the* Rev. G. F. WHIDBORNE, *M.A., and* Professor W. J. SOLLAS, *M.A., F.G.S.*

PART I.—*Lamellibranchiata. By the* Rev. G. F. WHIDBORNE.

The following shells occur in Britain. *Ostrea sphæroidalis,* a large hemispherical form from Yeovil Junction; *O. munda,* flat and pear-shaped, from the Cotswolds; *O. explanata* (Goldf.) and *O. knorri* (Ziet.); *Gryphæa abrupta,* Dundry, which mimics *Trigonia costata*; *G. cygnoides,* Brodwinsor, elongate with striated umbo, and *E. globula,* a miniature of *E. columba*; *Pecten fenestralis,* Dundry, unlike *P. retiferus* by having its tesseræ square, and *P. cornutus* (Qu.); *Plicatula Tawneyi,* Dundry, like *Pl. reticulata,* but trigonal, and *Pl. Buckmani,* Yeovil Junction; *Lima æpybolus,* Brodwinsor, like, but with more distant ribs than, *L. Renvieri* (St.); *L. annifera,* unlike *L. aciculata* (Gf.) by having a smaller anterior ear, and *L. alticosta*; *Cucullæa perlonga,* like *A. lata* (K. and D.), but smooth, and *Nucula nucleus* (Desl.); *Mytilus striatissimus,* Dundry, more ungulated than *M. pectinatus* (Sow.); *Myoconcha unguis,* Dundry, large, massive, and with sharp curved anterior, and *M. implana,* Dundry, a wide trigonal shell, with a straight hinge line almost as wide as itself; *Cardita ovalis* (Qu.), and *Moreana* (Bav.), *Thracia Studeri* (Ag.); *Terebratula Davidsonella,* small hemispherical with minute ribs, and *T. disculus* (Waagen).

PART II.—*Spongidæ. By* Professor SOLLAS.

The inferior oolite has not hitherto furnished any species of sponge to palæontologists in this country or abroad, we are therefore much indebted to my friend the Rev. G. F. Whidborne for the somewhat large collection of fossil sponges (fourteen species belonging to ten genera), which he has brought to light from this formation, and which he has placed in my hands for description.

Of Dictyonine Hexactinellidæ we have (*a*) belonging to the *Euretidæ,* (1) the new genus and species *Emploca ovata,* a very similar form to *Porocypellia* among the Staurodermata, but generically distinguished from it by the simple Euretid character of the skeletal nodes, and still further separated by the absence of a continuous dermal skeleton. In outward appearance, and in the characters of its canal system, it most nearly approaches *Scyphia radiata ovalis,* Quenstedt, which is found in the White Jura δ. (2) *Mastodictyum Whidborni* (n. g. and sp.), a thin foliaceous plate which buds off on the upper surface small mammillary processes, each of which is occupied axially by a cylindrical excurrent canal terminating in a sharply margined apical oscule. (3) *Leptophragma fragilis* (n. sp.) very similar to *T. foliata,* Quenst. (*b*) Belonging to the Meandrospongiæ, according to Zittel's classification, but naturally more closely connected with the preceding species, we have the new genus *Plectospyris,* with its two new species, *P. elegans* and *P. major.* This genus approaches most nearly to *Plocoscyphia,* but is distinguished from it by the simple imperforate character of its nodes. (*c*) Allied to the *Ventriculidæ,* we have *Calathiscus variolatus* (n. g. et sp.). This genus differs from typical ventriculites in having the nodes irregularly, not octahedrally, complicated, resembling in this respect *Dactylocalyx* more than *Myliusia.*

Of Lithistida, we have the Rhizomorine form *Platychoni tenuis.* Of Catagmidæ

(Pharetrones, Zit.), there are several species belonging to the Peronella and other genera.

Many of these species are scarcely separable from those occurring in the White Jura of the Continent. The characters of the deposits in which they are found indicate shallow water conditions, thus showing that the Hexactinellid sponges were at this time less characteristically deep-water dwellers than at the present day. The originally siliceous skeletons of Hexactinellids, Lithistids, and Catagmids have all alike undergone a complete replacement by carbonate of lime; the silica removed has been redeposited in quartzose granules and crystals, frequently replacing the calcic carbonate of associated corals and other fossils.

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6. *Eighth Report on the Circulation of the Underground Waters in the Permeable Formations of England, and the Quality and Quantity of the Water supplied to various Towns and Districts from these Formations.*—See Reports, p. 213.

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7. *Evidence of Wave-Action at a depth of* 40 *fathoms in the English Channel. By* Arthur R. Hunt, *M.A., F.G.S.*

The author described and exhibited a soda-water bottle trawled about 20 miles S.S.E. of the Start in a depth of about 40 fathoms. It is partially encrusted with marine organisms. The surface, where exposed, presents the appearance of being finely scratched or ground, and the embossed letters of the legend are chipped and abraded. Many of the encrusting serpulæ are in a fragmentary state. The bottle when received was about half full of a deposit consisting of quartzose sand, small stones, shells (both whole and fragmentary), and other organic débris. Thirty-eight species of shells have been recognised; two of them, a fusus and a single valve of pecten, were so large that they could only pass through the neck of the bottle in one position, the interior of it being slightly oval.

The abraded exterior surface of the bottle, the broken serpulæ, and the presence of stones and such large shells in the interior, indicated a considerable disturbance at the bottom of the sea at some time after the bottle had been deposited there. The fact that serpulæ were present at all proved that the disturbance was intermittent and not continuous. The intermittent character of the disturbance precluded its being referred to tidal currents, which would be constant in their action, and pointed to reciprocal currents set up by waves during violent storms. The fact that the exterior surface of the bottle in places presents the appearance of ground glass cannot be ascribed to any chemical action of the sea-water, as there is no corrosion of the interior surface; nor can the chippings of the embossed letters or the abrasion of the exterior surface have been in existence before the bottle fell into the sea, as they are unlike the wear and tear exhibited by any old soda-water bottle in common use. The fusiform shape of the bottle, presenting as it does no plane surface on which to rest, would render it liable to be rolled by any currents at the sea-bottom.

For further evidence of the action of waves on the bottom of the English Channel, the author referred to his paper on the Formation of Ripplemark. (Proc. Roy. Soc., 1882).

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8. *List of Works on the Geology and Palæontology of Oxfordshire, Berkshire, and Buckinghamshire. By* W. Whitaker, *B.A., F.G.S.*—See Reports, p. 327.

SATURDAY, AUGUST 26.

The Section did not meet.

MONDAY, AUGUST 28.

The following Papers were read:—

1. *Mention of an example of an Early Stage of Metamorphic Change in Old Red Sandstone Conglomerate, near Aberfoil. By* Professor JAMES THOMSON, *LL.D., F.R.S.*

The present communication relates to metamorphic changes noticed in Old Red Sandstone Conglomerate near Aberfoil, in cuttings on the new branch railway from Buchlyvie terminating at Aberfoil.

The author had an opportunity of seeing this on the occasion of a recent visit to the railway, through the invitation of Mr. Charles Forman, of Messrs. Formans and McCall, engineers of the line. Mr. Forman pointed out various geological features which were exposed to view in the cuttings for the railway. Among these were waterworn conglomerate pebbles, which had undergone distortion and partial crushing, obviously indicating that they must have been from some cause reduced to a semi-plastic condition.

The phenomena of these altered pebbles seemed to be of much interest in connection with considerations or speculations as to what might be the softening agency to which they had been subjected. Specimens were brought away; and some of them are now shown to the meeting.

By inspection of these specimens it may be observed that they have yielded in a plastic manner to the pressure of their contiguous neighbours, that they have been impressed one into another at the spots of mutual contact, and that they have bulged out and cracked open at intervening places between these spots of compression. The pebbles appear, many or most of them, to be quartzite.

At various places in the cuttings of the railway within the first mile of its course from Aberfoil, the Old Red Sandstone Conglomerate of the district was found to be altered in this way; but throughout the most of that space no such great alteration was to be found, as the pebbles generally appeared not to have been reduced to a plastic and yielding condition.

Questions must now occur for consideration and research, which however the author does not propose at present to answer, as to whether the softening influence was merely a high temperature producing a partial fusion of the stone; and, if so, how the heat came to be localized or applied at particular places more than others; also, whether hot water under great pressure, or hot gases, or vapours of volcanic origin, were concerned in producing the effects.

The author presumes that such phenomena as those he has described must have been already noticed in various localities; but he thinks the subject may yet be worthy of further research and consideration. From Mr. John Young, F.G.S., Under-Keeper of the Hunterian Museum in the University of Glasgow, he has learned that Dr. Page, in a lecture delivered by him before the Geological Society of Glasgow about 16 years ago, exhibited examples of similar quartzite pebbles from the Nethan Water, near Lesmahago, which were similarly cracked and distorted by the pressure of contiguous pebbles.

Addendum.

Since the close of the meeting the following list of references to authorities on like or allied phenomena has been prepared by Mr. W. Topley, F.G.S., Geological Survey of England:—

1795. J. Hutton: 'Theory of the Earth,' vol. i. p. 467 (Arran).
1836. J. Philiips: 'Geology of Yorkshire,' Mountain Limestone District, p. 14 (Old Red Conglomerate, W. Yorkshire).
1844. [R. Chambers]: 'Chambers' Journal,' Nov. 25.
1845. [Sir] W. C. Trevelyan: 'Quart. Journ. Geol. Soc.' vol. i. p. 147 (Arbroath and Stonehaven).
1850. W. Stevenson: *Ibid.* vol. vi. p. 420 (Old Red, Lammermuirs).
1855. [Sir] A. C. Ramsay: *Ibid.* vol. xi. p. 200 (New Red Conglomerate).
1855. J. Nicol: *Ibid.*, p. 545 (Stonehaven).
1857. A. Daubrée: 'Comptes Rendus,' vol. xliv. p. 823 (Experiments).
1860. J. Tyndall: 'Glaciers of the Alps,' p. 404.
1860. E. Hitchcock: 'Amer. Assoc. Sc. p. 156.
1861. E. Hitchcock: 'Amer. Journ. Sc.' vol. xxxi. p. 372.
1861. H. D. Rogers: *Ibid.* vol. xxxi. p. 440.
1862. E. Hitchcock: Sixth Ann. Rep. Maine Board of Agriculture (quoted in 'Quart. Journ. Science,' vol. i. p. 125, 1864).
1862. [Sir] A. C. Ramsay: 'Catalogue of Rock Specimens, Museum of Geology, London,' 3rd ed. p. 11, Silurian, Wales; p. 60, Old Red; p. 116, New Red.
1865. H. C. Sorby: 'Proc. Geol. and Polyt. Soc.' West Riding of Yorkshire, p. 458.
1866. J. Geikie: 'Quart. Journ. Geol. Soc.' vol. xxii. p. 513 (Silurian, Ayrshire).
1869. W. P. Blake: 'Amer. Assoc. Sc.' vol. xviii. p. 199.
1870. A. Geikie: 'Catalogue of Rock Specimens, Edinburgh Museum,' pp. 51, 55.
1871. 'Memoirs of the Geological Survey of Scotland,' Sheet 15, pp. 17, 21.
1874. H. C. Sorby: 'Impressed Limestone Pebbles' (Cardiff Nat. Soc.)
1875. W. Molyneux: 'N. Staff. Field Club Papers' for 1875, p. 103 (New Red, Trentham).
1879. A. Daubrée: 'Études Synthétiques de Géologie Expérimentale,' vol. i. p. 404 (Experiments).
1882. A. Geikie: 'Text Book of Geology,' p. 312.

N.B.—In the publications of Sorby (1874), Daubrée (1879), and Geikie (1882), references are given to authorities other than those noted above.

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2. *On Features in Glacial Markings noticed on Sandstone Conglomerates at Skelmorlie and Aberfoil. By* Professor James Thomson, *LL.D., F.R.S.*

When glacial striation is met with on rock faces, it may often be a matter of interest to find in which way along the direction of parallelism of the striæ the abrading or polishing ice must have advanced. Casual observers, unskilled in the scrutiny of glacial phenomena, may sometimes too hastily assume, when they find the lines of the striæ inclined to the horizon, that the ice has been moving over the striated rock-face or hill-side in the downhill direction of the striæ. The direction of the motion of the ice along the striæ, however, cannot generally be safely inferred from mere local configurations of the land; and, in some cases, the configuration of the land, whether locally regarded or considered in wide scope, may afford no decisive proof at all as to which way the ice has advanced along the striæ.

In the rather limited researches which the author has had opportunity to make in respect to glacial phenomena in geology, he has felt interest in seeking for indications presented by the striated rock-faces themselves, which might conclusively show in which way the ice must have advanced. He wishes, in the present paper, to make mention of one or two rather remarkable indications of this kind which he has met with in the last two years.

At Skelmorlie, on the Frith of Clyde, at a height of about 150 or 200 feet above the sea, he has found glacially striated surfaces, on red sandstone containing pebbles of quartz and of other kinds of stone. Many of these pebbles projected considerably out from the general smoothed and striated surface of the sandstone, and from each of such pebbles there extended to one side a ridge of the sandstone, like a tail, the sandstone being there worn away less than at other places devoid of the protecting influence of any hard protuberant pebble. The manner in which the protection had been given must have been this:—The ice, in passing over the protuberant hard pebble, must, in virtue of its plasticity, have had a groove moulded into it by the pebble, and this groove passing forward from the pebble in the motion of the ice, must have worn away the sandstone facing to it less than would the other parts of the ice-face wear away the sandstone facing to them. The length of the noticeable tail would depend mainly on the distance that the ice could advance before the groove in it would be gradually obliterated. A pebble of the size of a bean, for instance, might often be found to have a tail visible for a length of five or six inches, or perhaps from that to a foot, and larger pebbles might be seen to have tails two or three feet in length.

Again, on the recent visit to the railway cuttings near Aberfoil, referred to by the author in his previous communication, a remarkable example was found of a glacially worn and finely striated conglomerate rock face. The situation of this is at Ballanton, about a quarter of a mile from Aberfoil. The hard pebbles were of various sizes, and many might be of sizes such as those of beans, and eggs, and large potatoes. Some of them were worn away by the ice continuously with the surrounding sandstone matrix; but those of them which projected showed very conspicuous tails, many of which might be four or five feet long or more.

Various other indications, presented by the striated surfaces themselves, of the direction along the striæ in which the motion of the ice has been made, may occasionally be found. Doubtless none can be more strikingly remarkable than the tails extending from hard pebbles or other hard nodules, or hard veins, included in the ice-worn rock. The author wishes, however, to mention that on making minute examination, by a magnifying lens, of the scratches on worn quartz pebbles in the striated sandstone at Skelmorlie, he was able to find also in these very small markings, indications which appeared clearly to show the direction of the motion of the ice, and that these indications were perfectly in agreement with those given by the tails extending from the pebbles along the striated sandstone surface.

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3. *On the Equivalents in England of the 'Sables de Bracheux,' and on the southern limits of the Thanet Sands.* *By* Professor PRESTWICH, *F.R.S., F.G.S.*

The author dwells on the importance of establishing, in adjacent but separate basins, a certain number of well-defined horizons. The lignite and fresh-water beds of the Paris Lower Tertiaries and of the Woolwich series form one such zone, but he considers the generally accepted correlation of the beds beneath not satisfactory. The Bracheux sands are still, by all other geologists, placed on the level of the Thanet sands and of the Lower Landenian beds. Some years ago[1] the author saw reason to suppose they might rather be correlated with the lower beds of the Woolwich series, and in this opinion he is confirmed by the more recent researches of M. Deshayes, by whom many new species were described, and many rectifications made of the species in M. Graves's lists from the Bracheux beds.

[1] *Quart. Journ. Geol. Soc.* for August 1855, p. 219.

He shows that the lower Woolwich beds become glauconiferous as they range eastward through Kent; that the fresh-water element disappears and a marine fauna is substituted. This fauna contains such Bracheux shells as the *Cytherea Bellovacina*, *Nucula fragilis*, and several others; while the *Glauconie Inférieure* or Bracheux sands contain such characteristic Woolwich shells as the *Ostrea Bellovacina*, *Pectunculus terebratularis*, &c. Several of the shells are, it is true, Thanet Sand shells, but they also range up into the Woolwich series, whilst many characteristic Thanet Sand fossils, such as the *Pholodomya Konickii* and others, are wanting.

The author concludes that the Thanet sands are absent in the Paris basin, as they are in the Hampshire basin; that the sea of that period was limited to the south-east of England, Belgium, and French Flanders, and that it was not until the commencement of the Woolwich and Reading period that the Paris area was submerged and beds of this age spread over it. The molluscan fauna of the latter period has as much analogy with the London Clay series as with the Thanet sands. If this correlation be correct, then it would relegate that remarkable deposit of the Rilly sands, with its group of curious species of *Physa*, *Helix*, *Cyclostoma*, &c., to the middle of the Woolwich and Reading series, instead of to the base of all the tertiary series, where it is now placed. As the question involves the range of several tertiary genera and many other questions hinge upon it, the exact determination of this point is of much interest, and the author, while advancing his own opinion on the subject, invites further attention to it, as the English fossils are few in number, and there are many points connected with it still somewhat obscure.

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4. *Suggestions for a Revised Classification of British Eocenes. By* J. S. GARDNER, *F.G.S.*

Some modification in the classification of the Eocenes has become desirable, through the transfer of the Upper Eocene group of Edward Forbes to the Oligocene formation. The discovery of several distinct floras seems also to necessitate certain alterations, in order to bring periods, founded originally on changes in mollusca, into harmony with the more striking changes indicated by the plants. A grouping is suggested which separates the London clay from the Lower Eocene and brackets it with the Lower Bagshot beds as a Middle Eocene. The middle Bagshot series forms the Upper Eocene, while the Upper Bagshot may remain a member of the same formation or find a place in the Lower Oligocene.

The great change in climate which took place between the Lower and Middle Eocene as thus grouped, and which led to the migration of the older eocene floras towards the pole, is pointed out, as well as the constant presence of a great river in our area flowing from west to east throughout the whole Eocene period. While the Lower Eocene and London clay depressions travelled from east to west and caused an advance of the North Sea, the middle Bagshot depressions commenced in the south-west and led to an incursion of a southern sea, and also caused the river delta to shift south-west to Hampshire. In the Barton period the two seas united temporarily. The temperature began to decrease after the Headon period.

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5. *On the Classification of Oligocene Strata in the Hampshire Basin. By* J. W. ELWES.

The base of the Headon series at Long Mead End, Hordle, contains *Cerithium concavum*. At the top of the series a marine bed has been observed, which may be correlated with the Colwell Bay Venus-bed. The latter can be traced to the edge of Warden Cliff, and a similar Venus-bed is observed in Headon Hill. The author supports the view that the Colwell and Headon Venus-beds are one zone. He has observed the presence of *Cerithium concavum* and *C. ventricosum* above the marine bed at Colwell, as at Headon.

Professor Judd's list of Brockenhurst fossils contains 52 species from Colwell, not occurring at Brockenhurst; and 107 species from Brockenhurst, not found at Colwell; while only 20 are recorded from both localities. This does not read like a list of species from one formation.

At Headon occur about 30 per cent., at Colwell about 33, and at Brockenhurst (omitting corals) about 52 per cent. of species from below the Headon series. Professor Judd concluded that only $\frac{1}{5}$th of the Brockenhurst species occur in beds below the Headon series.

At Whitecliff a representative of the Venus-bed at Colwell occurs, and *below* it a representative of the Brockenhurst bed containing 69 marine species. Of these 51 occur at Brockenhurst, and 53·6 per cent. of them in beds below the Headon series. These numbers are gathered from Messrs. Keeping and Tawney's lists. The occurrence of abundance of *Cerithium concavum* at Whitecliff above the marine beds has quite recently been observed by Mr. Keeping.

The author concludes that there is only one middle marine group in the Headon series, with two zones of fossils, the Brockenhurst zone being the lower. He offers, as an explanation of the difficulty of correlating these beds with the continental, if the presence be admitted of *C. concavum* above the Brockenhurst marine bed, the suggestion that in the Hampshire area this species lived after as well as before the deposition of these beds, though apparently it did not survive the deposition on the Continent of the equivalent series of the Lower Tongrian.

He supports Professor Judd in obliterating the group called the Osborne series, chiefly on the ground of the difficulty of finding any natural line between it and the Upper Headon, but would class these beds with the Headon series, not with the Bembridge.

He also agrees with Professor Judd in obliterating the line of division made by Professor Forbes at the Black Band at Hampstead. The natural base of the Hampstead series is that proposed by Professor Judd—viz. the *Cerithium* band at the base of the marine beds.

6. *On the Outcrop of the Brockenhurst Bed, near Lyndhurst.* *By* E. B. TAWNEY, *M.A.*, *F.G.S.*

Fossils characteristic of the rich bed which he had been lately working in the railway cutting near Brockenhurst, were found by Mr. H. Keeping at Cutwalk Hill, Lyndhurst, in 1858. The well at Emery Down, closely adjacent, also yielded the same fossils in 1863. The excavations which the author had lately carried out with the assistance of the Rev. J. Compton of Minstead, on several sides of this hill show the succession of the beds to be, at the base of the hill, Upper Bagshot sands, next in ascending order freshwater Lower Headon, marine Brockenhurst bed, *Voluta geminata* zone, followed by beds not explored, but concluding with the freshwater Osborne marls at the top of the hill. The succession is therefore the same as at Whitecliff Bay.

The thickness of beds between the freshwater Lower Headon and the Osborne marls is about 100 feet. The Brockenhurst bed yielded a few of its characteristic fossils, but near the outcrop these are weathered, or have entirely perished. It seems hopeless to expect well-preserved fossils in pits of less than 20 feet deep.

In conclusion the discovery of the freshwater Upper Headon beds in the Roydon brickyard by Mr. H. Keeping, was announced. They are found to be at least 7 feet thick, and contain layers rich in *Potamomya plana*.

7. *On Subsidence as the Effect of Accumulation.* *By* CHARLES RICKETTS, *M.D.*, *F.G.S.*

There is no fact in Physical Geology more frequently recorded than that, whilst the deposition of sedimentary strata has been in progress, there has been simul-

taneously a subsidence of the earth's crust; though but little effort has been made to determine whether they are dependent on each other as cause and effect.

Borings in deltas prove that depression to a great extent has occurred whilst the accumulation was being deposited. The greater amount of detritus derived from hills and valleys is carried into the sea, but, instead of filling it up, the water becomes of a great depth at a few miles from the mouths of large rivers.

There was a progressive subsidence of the land during the Glacial period; this may be ascribed to the weight of accumulated snow, and of the newly-formed boulder-clay; a similar depression is occurring in Greenland, under a rapid increase of snow.

The carboniferous series above the limestone afford most satisfactory evidence that the amount of subsidence coincides with that of deposition; the surface of the limestone and the beds of coal furnishing sufficiently correct base-lines for determining the question. Near its southern boundary in Coalbrookdale, the carboniferous limestone is overlaid by millstone grit, the thickness of which, as well as of the coal-measures, is there very inconsiderable, compared with localities in Denbighshire and Lancashire. There is also apparent in numerous instances, even within a distance of a few miles, a considerable difference in the thickness of the strata between identical beds of coal. The most remarkable example recorded is that of the 'Thick,' or 'Ten-yard' coal of Dudley, which, from thirty feet of coal, and with two to four feet of 'partings,' has five miles towards the north separated into ten or twelve beds of coal, which combined are of the same thickness, but with the intermediate measures amount to 406 feet.—(*Jukes.*)

There must needs be a cause for this universal occurrence of subsidence with deposition of strata, the only efficient one being the weight of the accumulated material pressing down the crust of the earth resting upon a fluid substratum.

Elevation also happens on the removal of pressure, and 'those regions which have suffered the greatest amount of denudation have been elevated most.'—(*Captain Dutton*, U.S. Ordnance Survey.)

At the termination of the Glacial period, the land, depressed by its load of snow, became, upon this melting away, re-elevated to a certain extent. This, and the rising of the land at the present time in Norway and Spitzbergen, may be attributed to the removal of a thick covering of snow.

In elevated districts the highest parts are those in which there has been the greatest amount of denudation, and often consist of the lowest rocks in a geological series. Thus in North Derbyshire the highest land is composed of carboniferous limestone, from above which more than 5,000 feet of later carboniferous strata have been removed.

The author thinks that these depressions and elevations cannot be ascribed to secular cooling of the mass of the earth, since by such action the accumulation cannot also be accounted for; nor could the same agency acting only in one direction cause both depression and upheaval.

The concurrent phenomena of accumulation and subsidence, and their converse, demand serious and careful investigation; especially as in them may be found the great moving-power upon which depends the greater number of geological changes.

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8. *On the Cause of Elevation and Subsidence of Land.* *By* J. S. Gardner, *F.G.S.*

The paper claims that the evidence of the permanence of continents is inconclusive as regards eocene and præ-eocene periods, and inquires what the shallower regions of the Atlantic mean, if they do not mean a change of level at the sea-bottom. Assuming, with Sir C. Lyell, that at a given depth rocks are molten, and that under further pressure they are reconverted into solids of high specific gravity, the paper demonstrates that the outer envelope is susceptible to and gives way under any increased weight, and recovers when this is removed. The evidence relied upon

is that of coral isles, lava-flows, accumulations of ice, and of sediment in deltas, estuaries, and along sea-coasts. In these cases, unless there are counteracting agents, subsidence invariably follows, and littoral seas are thus areas of depression. The increasing pressure in deep oceanic basins acting on the fluid layer leads to the elevation of lines of least resistance into ridges or dry-land, these lines generally coinciding with coast-lines, and to volcanic outbursts. Geology demands pre-eocene communication between many lands. The elevation of land continuous between Europe and America in the north, during the Middle Eocene, was coincident with a cessation in the great formation of basalt, and its subsidence with a renewal of this. The conclusion is drawn that irregularities of surface have and will continue to become more and more accentuated.

TUESDAY, AUGUST 29.

The following Papers and Reports were read :—

1. *On the Geology of the Channel Tunnel. By* Professor W. BOYD DAWKINS, *M.A., F.R.S.*

The duty of examining the physical structure of the cliffs on either side the Straits of Dover, and of collecting all the data necessary for the purposes of a Channel Tunnel, having fallen to my lot, I think it not inopportune to lay the results of my inquiry before this meeting of the British Association. I will first of all deal with the English cliffs.

The Section of the English Cliffs.

The rocks exposed in the cliffs between Folkestone and St. Margaret's consist of the following in descending order :—

		Thickness
VI.	St. Margaret's Bay chalk	280 +
V.	Nodular chalk with flints	100
IV.	Chalk with few flints	100
III.	Lower white chalk	137 161
II.	Grey chalk and chalk marl No. 2 of Price	202 to 2
I.	Chalk marl No. 1. of Price = Upper Greensand of old authors	3 to 15
A.	The Gault (Topley)	100 to 120

Nos. VI., V., IV. constitute the upper chalk with flints, and III., II., I. constitute the lower chalk of the English geologists.

The Gault *A*, a stiff blue clay and impervious, forms the low line of cliffs, on the west side of Eastwear Bay, and disappears below low-water mark opposite the Abbot's cliff tunnel. It has been struck at St. Margaret's Bay in the deep boring at about 536 feet below *O. D.*

The lowest bed of the chalk, No. I., the chalk marl No. 1 of Price, is a clayey calcareous deposit generally impervious, but in some places containing so much (*glauconite*) sand, that it allows of the percolation of water. The sand gradually disappears in the upper layers, as far as the hard rocky chalk, which forms the base of chalk marl No. 2 of Price. From this point up to the top of the grey chalk, there is no great change in the physical character. The calcareous element, however, increases, and the clayey element diminishes. I have therefore in the preceding table grouped the chalk marl No. 2 of Price with the grey chalk, under the head of No. II., the difference being merely a palæontological one, the former being characterised by reefs of fossil sponges (*Plocoscyphia mæandrina*). A well-marked

yellow band forms the upper boundary, defining it from the lower white chalk without flints.

The lower white chalk without flints No. III. is composed at its base, of a hard nodular chalk, the grit-bed of Price, and it becomes softer and whiter as far as the first layers of flint, which form the arbitrary line of demarcation, between the lower and upper chalk. The latter, comprising Nos. IV., V., VI., looser in texture and more calcareous than the beds below, needs no special comment in this place. The beds dip steadily to the eastward at a low angle, so that the base of the cliffs to the west of Dover is composed of the lower beds, and to the eastward of the upper.

The French Cliffs.

The cliffs between St. Pot and Sangatte reproduce all the characters of those between Folkestone and Dover, the subdivisions being easily identified, and the thickness of No. II. being very nearly unchanged. The beds, too, dip to the east, but at a higher angle.

The continuity of these rocks beneath the Channel is proved by the researches of the French Channel Tunnel Company.

Faults and Dislocations.

The next question to be considered is, 'Are these strata broken by faults and dislocations?' Numerous faults and dislocations are to be seen in the English and French cliffs; but none of them are of great extent. The greatest throw on the English side, which I have observed, amounts to about eighteen feet, and on the French to twenty-five feet. In the lower part of No. II. the faults are closed fissures, not offering free passage to water, a fact proved not merely by the cliff-sections, but by the results of the experimental tunnel driven along the face of Shakespeare's Cliff. There they are merely dripping lines of weakness, easily stopped by ordinary appliances. On the French side the rocks are more broken, but no difficulty is experienced in drainage. The faults and dislocations in the beds above No. II. which form the cliffs to the east of Dover offer generally free passage to water and are open fissures. In Sir John Hawkshaw's boring at St. Margaret's Bay, a fissure three feet deep was met with, at a depth of more than 200 feet below the sea-level, and full of salt water. It is clear, therefore, that these rocks are penetrated by open water channels, which underneath the sea draw upon the salt water. This one, be it remembered, was casually hit upon in a small vertical boring. How many, it may well be asked, are likely to be intersected in a tunnel some miles long? They may be expected to prove a most grave element of danger in the course of working, and to be only made water-tight at a vast expense. Thus there is a difference of the greatest importance between No. II. and the beds above it, the faults and fissures which are closed in the one being open, and water-bearing in the other.

The Porosity of the Beds.

There is also the same difference to be noted in their porosity, for while the middle and lower parts of No. II. are, for all practical purposes, impervious, away from faults and dislocations, the beds above No. II. to the east of Shakespeare's Cliff and to St. Margaret's are highly charged with water, as might be expected from their being continuous with those which supply London with chalk water. They form one series of water-bearing rocks.

The impervious character of No. II. is due to the large percentage of clay mingled with the chalk. On analysis I find it to be as follows:—

	Per centum of clay
No. III. Lower white chalk at 80 feet above yellow band .	5·7
" " " 40 " " .	2·6
" " " 20 " " . = Nodular Chalk	18·5

		Per centum of clay
No. II.	Grey chalk, yellow band	10·5
	Upper grey chalk	12·0
	Middle	6·0
	Lower	33·0
	Cast-bed	15·0
	No. 4 of Price	16·0
	No. 3 of Price	40·0
	Chalk marl No. 2 of Price	31·0
No. I.	Chalk marl 1 near bottom (+ sand)	75·0
	Top of Gault at junction	45·0
	Bottom of shaft No. II.	62·0
	Tunnel end, July 1	55·0
	Tunnel end, July 15	42·0

It is clear from the above table that the clay diminishes as we ascend in the rocks, and that the lower strata of No. II. are the only strata in the series in which no difficulty is to be looked for, from the percolation of water. The three last analyses show that the amount of clay in the rocks penetrated by the tunnel, in front of the Shakespeare Cliff is very considerable, and that it diminishes as the tunnel rises to the higher beds. This change will be a most valuable index to the position of the end of the tunnel in carrying on the work in the rocks under the Channel.

The water locked up in the pores of the strata penetrated by the tunnel is proved by the analysis of my friend Dr. Angus Smith to be fresh water.

General Conclusions.

From the foregoing facts it may be concluded that:—

1. The lower beds of No. II. (chalk marl 2, and the lower part of the grey chalk) are the only strata in the chalk sufficiently impervious to allow of the construction of a tunnel in the dry.

2. That the outcrop of No. II. between Folkestone and the Shakespeare Cliff is the best position for a tunnel, which could strike the lower part of No. II. and remain in it throughout, so as to join the workings of the French Channel Tunnel Company which are being carried on in the same horizon.

3. That the faults in the lower part of No. II. do not allow of free percolation of waters, and are not likely to become a serious obstacle to the work.

4. That the strata above No. II. are so porous, and traversed by open fissures, that they allow of free access to water, both subaërial and marine, and therefore offer great difficulties in the way of the construction of a submarine tunnel which are not presented by the lower beds of No. II.

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2. *On the proposed Channel Tunnels in their Geological Aspects.* *By* C. E. De Rance, *F.G.S., Assoc. Inst. C.E.*

To those who have not studied the geology of the South-east of England, it may appear somewhat remarkable that the advocates of the scheme of the submarine Continental Railway Company state that the grey chalk will be found to be perfectly dry, while the white chalk will be found to be heavily charged with water, requiring constant pumping. But this apparent anomaly disappears when it is known that the geological horizon called by the East Kent people 'grey chalk,' is the formation so well known in Sussex and Hants by the name of the *chalk marl,* long since described by Dr. Mantell, and, still longer ago, in that much read book 'White's Selborne,' where its great fertility when decomposed into 'white malm,' and its value for hop- and wheat-growing purposes, is discoursed on.

The chalk marl of East Kent differs in no respect from the chalk marl of other parts of the country, in being practically waterless, and being the nearly imper-

meable material that supports the wonderful supplies of water given by the white chalk in many areas, amongst others, the area pumped by the Kent Waterworks, east of London, which raise about ten million gallons daily, and could easily double that quantity; while the chalk marl, in deep borings at many localities, has been found to be absolutely waterless, as at Kentish Town, Harwich, Southampton.

The Cliffs at Lydden Spout were measured by Mr. F. G. Hilton Price and myself in 1876, and were described by Mr. Price in a paper on the beds between the gault and upper chalk near Folkestone.[1] The height at this point was found to be 433 feet above the mean sea-level, and the thickness between the upper gault and first bed of flints (the upper chalk) to be 348 feet.

Of this thickness the lower white chalk forms the upper 150 feet; the upper part of this is the *craie marneuse,* and the lower part, the *craie noduleuse, à I. labiatus* of Dr. Barrois; the whole belongs to the Turonien of D'Orbigny; the lower 32 feet is the zone of *Cardiaster pygmæus* of Mr. Price, and is the 'grit bed' of local geologists, from its hardness being sufficient to turn the point of a pickaxe; the mass of the bed is made of comminuted fragments of inocerami and other fossils. The overlying bed is soft, but is not so pure a white as the upper chalk; water can freely percolate through it, but it is doubtful whether much can pass through the underlying 'grit bed.'

Beneath is the junction bed, or zone of *Belemnites plenus* of Mr. Price, four feet in thickness; it is of soft texture, and dark yellowish colour, and is of a poorer character. Below the junction bed is the grey chalk, 169 feet 9 inches thick, the upper 55 feet in the zone of *Belemnites plenus* of Dr. Barrois; the lower 93 feet is the *craie argileuse avec bancs durs à ammonites rhotomagensis.* The next 2 feet 9 inches is the well-marked 'cast bed,' which is marked and striped with mottlings of a darker colour; it contains a remarkable assemblage of fossils, which have somewhat of a gault facies, and it essentially marks the horizon of springs in this area; through it runs and issues the strong spring at Abbot's cliff, known as the Lydden Spout, this formerly drove a water-wheel, giving the power required for a whiting manufactory which once existed at the foot of the cliff; in later times it has provided water for the locomotives of the South-Eastern Railway.

Below the 'cast bed' is 19 feet of marly chalk, forming the zones of *Ammonites rhotomagensis* and *A. varians* of Dr. Barrois.

Beneath the marly bed forming the base of the 'grey chalk' is the chloritic, or rather glauconitic marl; it is traversed by hard reefs of sponges, which are occasionally converted into iron-pyrites, and are more or less entangled with the bones of *Ichthyosaurus*; it is the *craie marneuse,* with *Plocoscyphia mæandrina* of Dr. Barrois.

At Copt Point, the chloritic marl rests upon more sandy beds, which have been believed to represent the upper green sand of more western areas; but, according to Mr. Price and to Dr. Barrois, the facies it presents does not correspond with the upper green sand of the West of England, but is essentially a part of the facies of the chalk marl, and Mr. Price regards these sandy beds as the base of the chalk-marl, and calls it the zone of *Stauronema Carteri*; it is the equivalent of *Pecten asper* of Dr. Barrois, and on the horizon of the Warminster beds.

In Normandy M. Hébert classes the grey chalk and sandy beds as cénomanien, which he divides into three subdivisions:—

Craie grise	16 m. =	52½ feet
Grès calcareux	18 m. =	59 „
Glauconie sableuse	41 m. =	134½ „
		246

The water absorbed by the porous white chalk of North-East Kent, from the annual rainfall, follows the dip planes of the strata, and must circulate in the white chalk under the sea; and should the water be artificially abstracted in making the proposed tunnel in St. Margaret's Bay, it must inevitably affect the existing water

[1] *Quart. Journ. Geol. Soc.* vol. xxxiii. Part III. p. 431.

supply of Dover town and castle, and moreover, as the water is abstracted from the chalk, the latter will come into the condition in which it can absorb the waters of the sea; the amount so absorbed is limited by the degree of porosity of the chalk, but even if the amount be only one million gallons per day, for each mile of tunnel driven, it must inevitably very seriously affect the construction of a tunnel in this part of the chalk.

Their areas and absorption may be taken at:—

Lower Greensand	Square Miles	Average Annual Rainfall	Million Gallons per Day	Absorption at ⅓
Petersfield District		"		
Folkestone Sands—Midhurst to Kingsley .	18·8	36	27·17	9·05
Sandgate Clay	10	36	14·48	— ?
Hythe Sandstone—North Heath to Hindhead .	34·9	36	50·28	16·76
Total	53·7	—	.	25·81

The height of the springs and the consequent probable height at Southampton are given in the previous table.

3. *On the Synclinal Structure of the Straits of Dover.* By W. Topley, *F.G.S., Assoc. Inst. C.E.*

The author briefly described the physical structure of the border of the Wealden district, and showed that most of the great transverse valleys—those which drain the Wealden district—lie in gentle synclinal troughs. This is the case with the transverse valleys intersecting the chalk and lower greensand escarpments. The Darent intersects the chalk only, and in this instance the transverse synclinal affects the chalk area only; it does not extend so far south as the lower greensand.

The researches carried out by the French engineers over the bed of the Straits of Dover, have made known the exact outcrop of the gault over the sea-bed. From this it appears that the Straits coincide with a synclinal having its lowest point about one-third of the way from the English shore. This represents the old river valley which drained northwards through the chalk; the higher tributaries of this old river were the Rother and its branches, which now enter the English Channel at Rye.

It is probable that there were originally six rivers on the south side of the Weald corresponding with those on the north. Only four of them now remain. The fifth is represented by the Ashburn; this now enters the sea near Pevensey, but it once traversed the chalk about two miles east of Beachy Head. The sixth was the Liane; this now enters the sea at Boulogne, but it once traversed the chalk, and entered the English Channel a few miles west of the French shore.[1]

4. *Report on the Exploration of Caves of Carboniferous Limestone in the South of Ireland.*—See Reports, p. 240.

[1] The synclinal structure of the transverse Wealden Valley was noticed by Mr. A. Taylor in *Geol. Mag.*, dec. 2, vol. i. p. 456. Further details will be found in the Geological Survey Memoir on 'The Weald,' 1875, p. 276.

5. *On the Southampton Artesian Well.* By T. W. Shore, *F.C.S.*, *and* E. Westlake, *F.G.S.*

In bringing forward this subject on behalf of the town, we place before the Section such details as we hope may enable them to form an opinion on a question of much local importance, viz., whether it is possible, by an extension of the existing well, to utilise it as a source of supply to the town.

The amount of water yielded by the well, on the last occasion of pumping, in 1851, was 130,000 gallons per day. The quantity at present supplied to the town from the Itchen is from three to three and a-half million gallons, but this is a much larger quantity per head than is found to be sufficient for towns under a regulated system of supply. It thus appears that the well yields about one twenty-fifth part of the quantity required.

For the purpose of increasing the yield two methods are suggested. One of these is, to drive galleries or drift-ways in the chalk. The other, to continue the boring through the chalk into the upper and lower greensands.

We will first describe the present condition of the well, and then refer to the probable nature of the strata below the point reached by the boring.

The work of excavation was carried on from July 1838 till February 1851, at a total cost of 19,000*l.*, and reached a total depth of 1,317 ft.

A well was sunk by means of iron cylinders and brickwork, through 464 ft. of the tertiary beds. The diameter is 13 ft. at the top, and diminishes by successive stages to 7 ft. in the lower portion.

The beds passed through consist of: 2 ft. of soil; 74 ft. of lower Bagshot beds, consisting of sand and clay in alternations; 304 ft. of London clay, consisting of sandy clay, with seams of water-bearing sand, and pebble-beds towards the top; 84 ft. of plastic clay, with the usual bed of greensand at the base. The chalk was reached at a depth of 464 ft., where the masonry was terminated. The 7-ft. shaft was continued 99 ft. in the chalk. A boring was then made with a six and a-half inch auger to a further depth of 754 ft., making a total of 853 ft. in the chalk, or 1,317 from the surface. The chalk is stated to have contained flints, all but the last 10 ft. The bottom 15 ft. of the flinty chalk is described as blue and cloggy. The last 10 ft. contained veins of clay, and were very cloggy.

At this point the boring was stopped, the cost at that time being twice as great as it is at present, and the report of Mr. Ranger, the consulting engineer, being unfavourable to its continuance.

The mouth of the well is 140 ft. above the level of the sea, and the water stands at present at 40 ft. below the surface of the ground.

Most of the water appears to come from the chalk. Previous to the commencement of the boring in 1842, 20,000 gallons per day were raised; in 1844, after considerable progress had been made in boring, this increased to 50,000 gallons; and finally, in September 1851, to 130,000 gallons. The chalk thus supplies about five-sixths of the whole quantity.

In connection with the method of increasing the yield of a chalk well by driving galleries, we give a few particulars of the Brighton Waterworks, as an example of the application of this method to the supply of a large town.

Those who know the Brighton Downs will be aware that the rain forms no surface streams. It is entirely absorbed, and passes to the sea through fissures in the body of the chalk. Since the chalk is as retentive as it is absorbent, it seems probable that the drainage in chalk districts takes place almost entirely by means of these fissures. In the Brighton Works the fissures are found to follow the dip of the beds. They vary in size, up to a few inches in width, but are generally not more than three-fourths of an inch. The sides of these fissures are usually of the colour of mahogany, caused by the infiltration of small particles of the upper clays, and are polished by the continual friction of the water.

The plan adopted at Brighton is to sink wells, and drive tunnels or adits at the bottom of these wells in a direction parallel to the strike, so as to cut as many as possible of the fissures and intercept the water before flowing to the sea. In the

tunnels at Goldstone Bottom two enormous fissures were pierced at about 160 feet distant, each of which delivered at once quite 1½ million gallons per day. The total length of the tunnels at Brighton is 4,200 feet, or four-fifths of a mile. The quantity supplied is about 3 million gallons per day, but the amount that can be pumped daily without exhausting the wells is not less than 8 millions.[1]

Applying these facts to the case of the Southampton Well, it is obvious that the extent of the chalk north of Southampton is much greater than that to the north of Brighton. And if, as is probable, the rainfall on this area (about 1,000 square miles) is only partially accounted for by the rivers which flow through it, it follows that a portion must escape to the sea by permeating through the mass of the chalk; and if, as elsewhere, this permeation takes place along vertical fissures, there may be plenty of water in the chalk beneath Southampton, although little has been found by boring, for the chance of hitting one of these fissures by a bore-hole, 6½ inches in diameter, is obviously very small.

We have now to consider the beds below the point reached by the boring.

With reference to the depth of the Upper Greensand. The only place where the chalk has been penetrated in the Hampshire Basin is at Chichester. It is there 790 feet thick. In the Southampton well 850 feet have already been passed through. Since the chalk becomes thinner towards the west we might have expected that the thickness at Southampton would have been less than at Chichester. At any rate this consideration, taken with the fact that the boring is now in chalk with seams of clay (doubtless the lower part of the chalk marl), renders it probable that the chalk is now nearly penetrated, and that of the 20 to 50 feet estimated by Mr. Ranger as still remaining to be pierced, the smaller estimate is the more probable. The thickness of the upper greensand in Compton Bay and the Isle of Wight generally is 150 feet, and the gault 100 feet. At Devizes and Swindon, Mr. Prestwich gives the same thicknesses. Phillips also gives the gault west of Devizes at 80 feet. At Petersfield the greensand and malmrock is 80 feet and the gault 100. In the Vale of Wardour, Mr. Andrews estimates the upper greensand at about 150 ft. and the gault at 75 ft.

From these data we infer that the thickness of the upper greensand beneath Southampton may be taken at from 100 to 150 feet, and that of the gault at about 100. Its area of outcrop extends around Southampton in a roughly elliptical form, and distant from it from twenty to thirty and forty miles. The extents of the different areas in square miles as drawn on the Geological Survey Maps are given in the following table; also the average rainfall on the same areas (for which we are indebted to numerous local observers). Taking the absorption at one-third of the rainfall, the quantity passing underground from each district is as follows:—

Upper Greensand	Square miles[2]	Average annual rainfall	Million gallons per day	Absorption at one-third
Petersfield District—Cocking to East Worldham	18·7	36″	28·95	9·65
Three-quarters of Kingsclere Inlier	2·7	30	3·24	1·08
Three-quarters of Shalbourn Inlier	2·3	30	2·76	·92
Vale of Pewsey, South Side . .	23·0	33·5	30·94	10·31
Westbury District—Urchfont to Whitbarn	12·4	34·8	17·38	5·79
Vale of Warminster	16·8	36·3	24·48	8·16
Kilmington and Stourton District .	12·3	36	17·71	5·9
Vale of Wardour, North Side. .	4·7	36	6·84	2·28
Shaftesbury District — Barford to Stour Valley	20·4	39	31·85	10·61
Total . .	113·6	—	164·15	54·7

[1] These particulars are from a valuable paper by Mr. Easton (Report of the Brighton Health Congress, 1881).

[2] Traced, and weighed to ·01 of a mile.

When this Section met here last, Dr. Buckand advised that the levels at which the springs from the greensand find their issue should be ascertained, especially near Petersfield. This we have done, and thence have deduced the approximate height to which the supply from each area may be expected to rise in the well. The results are as follows:—

District	Height of Springs above Sea-level	Distance from Southampton	Height of Water at Well
Upper Greensand			
Petersfield { Treyford	210	—	--
Petersfield { Petersfield	300	$18\frac{1}{2}$	150
Petersfield { East Worldham	390	—	—
Kingsclere	340	$27\frac{1}{4}$	137
Pewsey—Avon, at Wivelsford (estimated)	340	32	123
Warminster—Wiley, at Boreham Bridge	337	37	112
Wardour, Shaftesbury—Nadder, at Barford	200	$24\frac{1}{2}$	87
Lower Greensand			
Folkestone Sands—Petersfield	212	21	100
Hythe Sandstone—Rother, at Sheet Mill	175	22	80

The deep well at Chichester penetrates into the upper greensand, which is there about 80 feet thick. The supply of water from it is, and always has been, small, at no time exceeding 2,000 gallons per day. It appears, however, that when the boring was stopped in 1844, about 370 feet of the bore-rod and the slush-pipe at the end of it were left in the bore; and as there were no pipes used in the sand it is possible that the lower part of the bore may have been filled in again. Under these circumstances the smallness of the supply will hardly enable us to infer what it would be in other cases.

Coming now to the lower greensand, or sands of the Neocomian formation, these occur, as a gathering-ground with reference to Southampton, only in the Petersfield district. They consist, from the top downwards, of—

The Folkestone Beds, consisting of sand and carstone, about 100 feet.

The Sandgate Beds, consisting of sandy clay, sand, and ironstone, about 75 feet.

The Hythe Beds, consisting of sand, with some sandstone and chert, 200 feet.

Making an aggregate thickness of about 400 feet.

Beneath these are the Atherfield and Weald clays.

In the Vale of Wardour Mr. Andrews informs us that there are a few feet of what may be lower greensand strata.

If this is the case, it follows, as Southampton is 28 miles from this point, and 21 from Petersfield, that their thickness beneath Southampton may be taken at about half of what it is at Petersfield, *i.e.* 200 feet.

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6. *Tenth Report on the Erratic Blocks of England, Wales, and Ireland.*— See Reports, p. 243.

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7. *Third Report on the British Fossil Polyzoa.*—See Reports, p. 249.

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8. *On the Formation of Flints. By* Professor W. J. Sollas, *M.A., F.R.S.E., F.G.S.*

The ultimate source of the silica, of which flints consist, is admitted to be found in the felspars of igneous rocks. These, upon decomposition, yield about equal pro-

portions of silicic acid and clay. Thus the great clay-deposits of the earth's crust indicate a correspondingly large quantity of silica which has been carried in solution into the sea. That sea-water contains but the merest trace of silica, proves how effectually it is removed by sponges, radiolaria, and diatoms, in the formation of their siliceous skeletons, and there is no other way in which solid silica can be deposited in the open sea than through organic agency. Since modern calcareous ooze always contains a certain percentage of siliceous skeletons, it has been concluded that these were also present in the ancient ooze of the chalk; since they have disappeared from the chalk as it now exists, while flints have made their appearance, it has been suggested that the latter have originated by the transformation of the former. This conclusion has been confirmed by the observations of the author, who, together with Zittel, has shown that the silica of siliceous organisms has by no means the insolubility which has till recently been attributed to it; and next by researches of the author on incompletely formed flints, which have shown that the first step in their formation is the replacement of a certain quantity of chalk by silica, the cocco-liths, foraminiferal and other calcareous shells becoming siliceous pseudomorphs, which retain all the markings, even to the very finest, of the original tests. A further quantity of silica is next deposited, filling up the chambers of the foraminifera and the interstices of the siliceous chalk; in this way a white or grey flint is produced. If silica continues to penetrate the nodule and to be deposited in it, the grey flint loses its opacity and whiteness, and becomes converted into black translucent flint. A nodule is seldom, however, uniformly black throughout, certain portions remain in the previous grey-flint stage, forming light-coloured spots and blotches on a dark ground; if the white and black flint form alternate layers, then we have the phenomenon of 'banded' flint. A specimen in the Bristol Museum shows the formation of banded flint in an exceptionally clear way; the centre remains in the 'white' stage, the exterior is black; between the two is a region of agate-like bands of black and white flint, the white bands, terminating at their ends as irregular capes or promontories, which project into the black flint: while continuing their direction, are little outlying islands of white flint, which exactly resemble the spots and blotches of an ordinary black nodule. An examination of this specimen renders it clear that the nodule was originally grey throughout, silica continuing to enter it from without converted the exterior into black flint; but the process having stopped short of completion the centre remained unchanged, while between the centre and the exterior the intermediate zone remains in an intermediate state as banded flint. Thus the grey, banded, and black flints—the distinction between which has long been recognised—are shown to be but so many different stages of one and the same process.

WEDNESDAY, AUGUST 30.

The following Papers and Report were read:—

1. *Problems in the Geology of the Channel Islands. By the* Rev. EDWIN HILL, *M.A., F.G.S.*

Attention is directed to the scanty information existing with reference to these islands and the field of research they offer. McCulloch, Ansted, Liveing, have written on them, but much remains unknown.

The age of the rocks may be archæan, but requires fixing, and their relations to surrounding areas have still to be made out.

The stratigraphy of the separate islands has been worked out by Liveing, fully for Sark, partially for other islands, but his results require confirmation and extension. The mutual relations of Sark and Guernsey are given, but the rest are entirely unknown.

The petrology of the main masses has been partially treated, but more information is needed, and the dykes and veins are undescribed. They are interesting and varied. Among them is true mica trap.

The physical geology has been admirably treated by Ansted.

The islands offer a field for the investigation of the distinctive characteristics of dykes, veins, &c., and the study of archæan rocks.

The proper investigation requires a resident.

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2. *Notes on Alpine Post-Carboniferous (Dyassic) and Triassic Geology. By the* Rev. A. Irving, *B.Sc., B.A., F.G.S.*

This paper is intended to call the attention of English geologists to the most recent results obtained in Alpine geology by such observers as Gümbel, Von Hauer, Mojsisovics, Theobald, Zittel, and Pichler (not to mention others), and so to supplement the author's papers recently published in the 'Geological Magazine' on the Post-carboniferous and Triassic systems. Some recent observations by the author of the paper are also contained herein.

Of the Post-carboniferous (Dyassic) system, observation so far has failed to detect the presence of any deposits on the north side of the crystalline axis of the Alpine chain; the triassic strata rest at once upon metamorphosed rocks of Silurian age (Von Hauer). On the south side the principal deposits are comprehended under the term *Verrucano* (grey and red-brown conglomerates and breccias, with red sandstones, and occasional thin beds of lignite or coal). Views as to the true horizon of these beds are as yet divided; Von Hauer refers them to the lowest division of the Trias, at the same time admitting the propriety of Gümbel's view, that they may be the equivalents of the Rothliegende of Germany. The latter writer even considers that strata analogous to the Zechstein of Germany may be recognised in the Alps.

The enormous display of *volcanic activity* recorded in the Rothliegende of Germany is found repeated in the Alps in Post-carboniferous times. As an illustration of this the author gives some observations made within the last few weeks on the interstratification of ancient acid lava-flows (so-called porphyries) and bedded volcanic 'ash' of the Rittner Horn, one of the former centres of activity which produced the 'porphyries' of the Bozen district, the most extensive known in the world. The mountain is a true 'stratified cone,' preserving at its summit about a half of its ancient crater-walls. It is a remarkable illustration of the propriety of classifying the 'porphyries' among the 'Older Eruptive Rocks,' as maintained some time ago by Credner.

Transition Beds.—Gümbel considers the dark *Bellerophon*-limestone of the Puster Thal, as well as the Grödner sandstone at Neumarkt, near Bozen, the white Schwaz limestone in the Inn Thal, and some other deposits to be properly placed here, though others would place them in the Dyas. Their organic remains, he remarks, do not give them 'a pure Dyassic character, but very much more that of a transition series from the Dyas to the Trias' (vide *Anleitung zu geologischen Beobachtungen in den Alpen*).

Alpine Trias.—Sections of these deposits—one on the north slope, through the Steinernes Meer, near Saalfelden (after Mojsisovics)—another on the south across the valley of St. Cassian (taken by the author within the last few weeks), are described, and their correlation pointed out, in order to illustrate the completeness of the Triassic system as developed in the Alps, the clear sequence which has been established among its sub-formations, and the soundness therefore of the view propounded by Professor Credner, and quoted by the author in another place, that the key to the true geological history of Triassic times is to be found in the Alpine Trias.

The importance of the views maintained by so high an authority as Professor Gümbel as to the transition character of certain deposits is insisted upon; at the same time hasty judgment, while awaiting (for a few years) the results of more extended observations, is deprecated.

3. *Summary of Reports of the Committee on Underground Temperature. By* Professor J. D. Everett, *F.R.S.*—See Reports, p. 74.

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4. *Notes on the Geology and Mining of the United States of Colombia, S. A. By* Robert B. White.

These notes refer specially to the States of Cauca and Antioquia, which comprise the country between the 1st and 8th degrees of north latitude, and extend from 120 to 150 miles eastward from the Pacific coast. The eastern and western chains of the Andes, which run from south to north through this region, are distinct in their general characters. The eastern chain is almost all volcanic, whilst in the western there are no volcanoes north of the 2nd degree, and the rest of the Cordillera is composed of granites, granitoid rocks, and diorites. The upheaval of the eastern chain has raised the strata of the Cretaceous formation to a height of 8,000 feet above the sea-level; but on the western slopes of the western range these strata are found only a few hundred feet above the sea, and are almost undisturbed.

Eruptions of igneous rocks have taken place in all ages between the two chains of mountains, and the rocks of the valley of the river Cauca, which with its tributaries occupies the space enclosed by the two Cordilleras, are metamorphosed and crystallised to an extraordinary degree.

The formation of an immense number of metalliferous veins seems to be the natural result of this development of igneous rocks.

The sedimentary strata are Laurentian, Silurian, Jurassic, Cretaceous, Tertiary, and Post-tertiary. The Cretaceous beds contain good coal, limestone, and iron ores. The Post-tertiary alluviums are nearly all auriferous, but although the upper beds have been worked, the bed rock or old river channels have not yet been sought after. It is probable that they are as rich as those of California. In recent alluviums in the valley of the Cauca, remains of Mastodons have been found under circumstances which indicate that these animals were coexistent with man. Platinum, iridium, molybdenum, copper, lead, and zinc are found in workable quantities. Gold and silver are very abundant, and are the only metals mined for. It is not a fact that platinum has ever been found in a lode in Colombia, but the author has recently found iridium in appreciable quantity in a gold lode in the State of Antioquia. Diamonds are known to exist. Rubies and sapphires of large size are to be found in abundance in the State of Cauca, but the natives have not tried to turn this wealth to account.

The gold-mining is very interesting. Besides being found in the alluviums, gold exists in lodes of all ages, from the oldest granites up to a post-cretaceous period. The formation of gold and silver lodes in most abundance took place after the cretaceous period. In other countries the gold veins are usually confined to a limited group of rocks. The Silurian is usually considered to be the principal formation for gold, but in Columbia it is quite of secondary importance, although no doubt a great part of the alluvial gold was derived from the denudation of the older rocks which was effected upon the grandest scale imaginable. There is a great difference in the standard or fineness of the gold, according to its age, and the oldest gold is the best. It is found ranging from twelve to twenty-three and a half carats fine. According to the age of the lodes different metals are predominant in their association with the gold. In the oldest lodes copper is most common, and in the newest lead is the principal companion of the precious metals. When pyrites and galena are plentiful in a well-constituted auriferous lode, it is generally found that the gold will rather increase than diminish in quantity as the workings deepen. But lodes which are not well-mineralised are most often richest on the surface. Common arsenical pyrites is not a good companion for gold when it is not accompanied by other sulphides. Pyrites is a general companion of gold, but it is not every class of pyrites that is so, and lodes of different ages are characterised by different classes of pyrites. There are also several varieties of galena, which are more or less

favourable as associates of gold and silver. Gold is not found in combination with any metal except tellurium. Instances are found in which it would appear that when the pyrites in a gold lode has decomposed, some gold has been dissolved by the permeating waters and has again been crystallised in the cavities of the quartz, in a form distinct from that in which it existed previously. It is remarkable that a pyrites containing manganese is always a good matrix for gold. In some lodes there is evidence of the quartz having been formed first, and the metalliferous contents afterwards. Such lodes are very irregular in their yield. Carbonate of lime is a rare gangue for gold, but where it does occur it is very productive. The great variety of the lodes in Colombia enables the miner to acquire so many data for comparison, that he is able to distinguish the trustworthy from the untrustworthy lodes with a certainty perhaps unknown in other countries.

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5. *Report on the progress of the International Geological Map of Europe.* See Reports, p. 241.

Section D.—BIOLOGY.

President of the Section—Professor Gamgee, M.D., F.R.S.

DEPARTMENT OF ANATOMY AND PHYSIOLOGY.

THURSDAY, AUGUST 24.

The President delivered the following Address:—

On the Growth of our Knowledge of the Function of Secretion, to which is prefixed a Brief Sketch of the Writings of the late Professor Francis Maitland Balfour.

When the Council of the British Association did me the honour of asking me to preside over this Section, it occurred to me that a suitable subject for the presidential address would be a Survey of the Growth of our Knowledge of the Function of Secretion; for no subject, which has recently been the object of minute study by animal physiologists, is more likely to interest all devoted to biological pursuits, however diverse. I accordingly propose to direct your attention, for the greater part of the time at our disposal to-day, to what appear to me to be the most important and the most interesting of the researches bearing on this subject.

Before, however, entering upon the proper subject of this address, it would ill become me as president of this Section were I not to speak to you, however imperfectly, of two great losses which we have sustained, and which have saddened, and still sadden, the hearts of many of us. The year 1882 will long be memorable, and sadly memorable, as a year during which English biology sustained irreparable losses. So much has lately been written concerning that veteran in science, Charles Darwin, who will figure in the history of the human intellect with such men as Socrates and Newton, that I feel no words of mine are needed to add to your sentiments of admiration and respect. He has made for himself an imperishable reputation as one of the subtlest, most patient, and most truthful observers of natural phenomena. His powers as an observer were, however, almost surpassed by his ingenuity as a reasoner, and his power to frame the hypotheses most apt, in the actual state of science, to reconcile all the facts which came within the range of his observation. We remember the time when the name of Charles Darwin, and the mention of the theories connected with his name, awakened, on the part of many, sentiments of antagonism and of unreasonable opposition. But we have lived to witness, what I may term, a great reparation. Even those who did not know the man, and the qualities of mind and heart which endeared him to so many, have come to recognise that in his work he was actuated by a single-hearted desire to discover the truth; and, after calm reflection, they have conceded that his studies and his views, like all studies and all views which are based upon the truth, not only are not irreconcilable with, but add to our conceptions of, the dignity and glory of God. And here I may be allowed to remark that it is impossible to study the writings of Darwin, and especially the one in which he treats of 'The Descent of Man,' without recognising an undercurrent of reverent sentiment, which in one or two places finds expression in words telling us that man differs from the animal creation, if not in physical characteristics which cannot be bridged over, at least in moral attributes and in the 'ennobling belief in God,' by his power of forming

that conception of the Deity which, to use Darwin's own words, is 'the grand idea of God hating sin and loving righteousness.' [1]

We cannot help mourning for our great ones, though they be taken from us in the fulness of years, and when their labours have been so numerous and so productive that we marvel that they have been able to achieve so much within the span of a single life; but our grief is immeasurably greater when the man of genius is taken from us in the plenitude of strength, as it were upon the threshold of a life full of extraordinary promise.

Francis Maitland Balfour, whose sudden death has so recently cast a gloom over us all, was a man who appeared destined to advance our knowledge of animal development more than it had been advanced by the labours of any one of his predecessors. His death recalls the train of thought which we have pursued when reflecting upon the lives and works of such men as Mayow and Bichat, Gerhardt and Clifford. If so much could be achieved in so short a life, what great benefits would science not have derived, what remarkable steps in advance might not have been made, had it been given to these great minds to work on for the good of their race during a lifetime of ordinary length. It must be sufficient for us that it was destined otherwise; and, in mourning for our departed friend, we may at least reflect that we would not have had him less worthy of our admiration in order that we might mourn him the less.

The Researches of Francis Maitland Balfour.

At the risk of having to be somewhat brief in my discussion of the subject proper of this address, I must yield to the impulse which leads me to give you some account of Balfour's work.[2]

Having been educated at Harrow, Balfour entered Trinity College, Cambridge, in the year 1870. His friend and master, Michael Foster, has told us how, from the very first, besides engaging in systematic studies which he was able to pursue with no small degree of success, he devoted himself with passion to original research. At the very outset Balfour engaged in work which led to speculations of a fundamental and far-seeking nature, and of the three embryological papers[3] which he wrote before taking his degree, two related to questions which occupied his attention in a special manner to the end. One of these, 'On the Development and Growth of the Layers of the Blastoderm,' contains several statements not afterwards maintained; for instance, as to the independent origin of the mesoblast in the chick, where it is said 'neither to originate from the epiblast nor from the hypoblast, but to be formed coincidentally with the latter, out of apparently similar segmentation cells.' The other, 'On the Disappearance of the Primitive Groove in the Chick,' calls attention to, and corroborates Dursy's discovery of seven years before, and closes with a suggestion of the great hypothesis (afterwards elaborated) that the primitive streak is a lingering remnant of the blastopore. Balfour also wrote, whilst an undergraduate, 'On the Development of the Blood-vessels in the Chick,' but it may be doubted whether he advanced our knowledge of this obscure subject.

The 'Elements of Embryology,' by Michael Foster and Balfour, appeared (1874) shortly after Balfour had taken his degree (1873), and Foster has generously recorded how great was the part his pupil took in the production of this book. The month after taking his degree he made his first journey to Naples, and it was whilst working there that he entered upon his remarkable investigation on the development of Elasmobranchs. The natural outcome of Gegenbauer's exposi-

[1] *The Descent of Man and Selection in Relation to Sex.* Second edition (1874), page 144.

[2] In the preparation of this part of my address I have been very greatly aided by one of Balfour's pupils, my nephew, D'Arcy W. Thompson, Scholar of Trinity College.

[3] *Studies from the Cambridge Physiological Laboratory.* Part I., 1873. *Quarterly Journal of Microscopical Science*, vol. xiii. 1873.

tion[1] of the primitive character of this group was that increased interest should attach to all researches on its embryology. To an introductory account of the embryology of Elasmobranchs[2] Balfour owed, I believe, his fellowship at Trinity College, and from that time onwards until 1878 he pursued the investigation at Naples and in Cambridge. The collected results appeared in 1878, as 'A Monograph on the Development of Elasmobranch Fishes.' No research upon a limited group ever contained more numerous or more wide generalisations, extending over the whole domain of vertebrate embryology. I may dwell for a few moments upon some of its most interesting sections.

The structures which we are now familiar with as 'head-cavities' are described for the first time, and named; their relation to the cranial nerves and their resemblance or equivalence to the muscle plates of the body are pointed out; and Balfour seizes upon their value in throwing light upon the great problems of the segmentation of the head and the segmental value of the cranial nerves. In particular the 5th nerve and the 7th, with the auditory, are specified as the segmental nerves of the mandibular and hyoid segments. The short, but very important, notice of the sympathetic system showed that its ganglia developed on branches of the spinal nerves, and that it was therefore a product of the epiblast.[3] The primitive features of the mesoblast and notocord and their hypoblastic origin are described,[4] and furnish material for the comparison afterwards instituted in the 'Comparative Embryology'[5] between their development in Elasmobranchs and their still more primitive origin in Amphioxus, as diverticula of the archenteron. A very able chapter on excretory organs concludes this monograph. This subject had engaged Balfour's attention very early, and his introductory account of Elasmobranch Development contains his discovery of segmental organs in Elasmobranchs, —a discovery made independently but simultaneously by Professor Semper. These organs are shown to develop in the mesoblast, and are compared with the segmental organs of annelids.

A paper published in 1876 gives a singularly clear and thorough *résumé* of our knowledge of the development of the urino-genital system; and the diagrams there given, illustrating the homologies of the male and female urino-genital organs, are wonderfully simple and instructive. Shortly after the publication of this paper. Balfour became a Fellow of the Royal Society, from which he received a Royal Medal in 1881.

Among the interesting points that Balfour had made clear in connection with the spinal nerves of Elasmobranchs, was the fact that the anterior and posterior roots arise alternately, and not in the same vertical plane. He sought for an explanation of this in Amphioxus at Naples, in 1876. Owsjannikow and Stieda had discovered that the nerves of the opposite sides in Amphioxus arise alternately, and Stieda further stated that the nerves of the *same* side arise alternately from the dorsal and ventral corners of the cord. Stieda considered that two adjacent nerves were together equivalent to a single spinal nerve of higher vertebrates. Balfour[6] found no trace of difference of level in the origin of nerves on the same side, *i.e.* he denied the existence of ventral or anterior roots; and afterwards, in investigating the cranial nerves of higher vertebrates, and being unable to find any trace of anterior roots, he framed the bold hypothesis[7] that the head and trunk had been differentiated from each other at a time when mixed motor and sensory posterior roots were the only roots present, and that cranial and spinal nerves had been independently evolved from a common ground-plan.

Balfour's investigation of the development of the ovary was incomplete when his work on Elasmobranchs appeared; and he continued to work at this subject,

[1] Gegenbauer, *Das Kopfskelett der Selachier*, 1872.
[2] *Quarterly Journal of Microscopical Science*, vol. xiv. 1874.
[3] *Elasmobranch Fishes*, p. 172.
[4] Ibid. pp. 49, 85, 92, 104.
[5] *Comparative Embryology*, vol. ii. pp. 243-246.
[6] *Journal of Anatomy and Physiology*, vol. x. 1876.
[7] *Elasmobranch Fishes*, p. 193, *Comparative Embryology*, vol. ii. p. 380.

both in Elasmobranchs and Mammals, publishing a paper upon it in 1878.[1] A paper published in the same year, on the 'Maturation and Impregnation of the Ovum,' contained the very ingenious suggestion that the casting out of the polar bodies prevents the ovum developing by itself into a new individual, *i.e.* prevents parthenogenesis; and Balfour points out that parthenogenesis is practically confined to the arthropoda and rotifera, which are the only two groups in which polar bodies are not known to occur.

Balfour still continued, now in conjunction with Sedgwick, his researches on the urino-genital system, and described, among many other new points, the existence of a head-kidney (pronephros) in the chick.[2]

In this year, Balfour also investigated[3] the early development of Lacerta, and pointed out the presence of a primitive streak and of a neurenteric canal. This investigation confirmed his belief in the hypothesis previously quoted that the primitive streak is the relic of a blastopore.

At this time Balfour was working hard at his text-book of 'Comparative Embryology.' His published papers were no less numerous than before, but consisted in part of extracts from the more speculative chapters of the forthcoming book. He, however, published a paper,[4] containing the results of work scattered over two years, on the development of Spiders. He also published a paper[5] on the skeleton of the paired fins, based upon his work on Elasmobranchs. In this he contests the views of Gegenbauer and Huxley, that the primitive fin consists of a central multi-segmented axis with many lateral rays, and is most nearly retained in Ceratodus; he rather considers the primitive form to be a longitudinal bar running along the base of the fin (basipterygium), and giving off at right angles series of rays which pass into the fin. He adheres to the view expressed in the 'Elasmobranch Fishes' (p. 101) that the vertebrate limbs are remnants of two continuous lateral fins.

Another important paper of the same year dealt with the placenta. Balfour supposed that in the primitive Placentalia, simple fœtal villi, like those of the pig, projected from the discoidal allantoic region of the chorion into uterine crypts. The deciduate discoidal placenta of Rodents and Insectivores is the first stage in advance of this primitive type. Then along different lines diverge the zonary placenta of Carnivora, and the diffuse placenta of Suidæ, Lemuridæ, &c.; and the latter becomes contracted down to the discoidal placenta of man, a form in no way to be confounded with the primitive discoidal placenta of Rodents.

He engaged also, in conjunction with Mr. Wm. N. Parker, in a very important research, to be published in full in the 'Philosophical Transactions,' on the 'Structure and Development of Lepidosteus.' This paper contains an immense amount of new matter, both anatomical and embryological, and shows that Lepidosteus, though a true ganoid, has very marked teleostean affinities.

Balfour's last published paper,[6] which appeared during his recent illness, was written with the assistance of Mr. Deighton, and related to the germinal layers of the chick. This paper describes, in a very beautiful way, the double origin of the mesoblast, partly from an axial strip of epiblast in the line of the primitive streak, and partly as two lateral plates differentiated from the hypoblast in front of the primitive streak.

Before his last, fatal journey, Mr. Balfour was engaged in preparing a new edition of the 'Elements of Embryology,' and in producing a very elaborate memoir on the 'Anatomy and Development of Peripatus.' He had previously investigated that animal, in 1879, and had cleared up the matter of its segmental organs (overlooked by Moseley), and demonstrated the presence of ganglia on its ventral nerve-cords.

Mr. Balfour became a member of this Association in 1871, the year after he

[1] *Quarterly Journal of Microscopical Science*, vol. xviii. 1878.
[2] *Proceedings of the Royal Society*, vol. xxvii. 1878.
[3] *Quarterly Journal of Microscopical Science*, vol. xix. 1879.
[4] *Quarterly Journal of Microscopical Science*, vol. xx. 1880.
[5] *Proceedings of the Zoological Society*, 1881.
[6] *Quarterly Journal of Microscopical Science*, vol. xxii. 1882.

entered Trinity College. At the brilliant Belfast meeting in 1874 he read his first paper before the Association on Elasmobranch Fishes; and this paper and Balfour's share in the keen discussion which followed are still remembered with admiration by many. In 1880, at Swansea, he delivered an address, as Chairman of the sub-section of Anatomy and Physiology, dealing with the mutual services rendered by the evolution theory to embryology, and by embryology to the evolution theory, with special reference to the developmental history of the nervous system. In 1881, he was appointed one of the two General Secretaries.

But the great text-book of comparative embryology [1] is the real monument of Balfour's fame. It is impossible to convey an idea of the merits of this book. It grappled with the enormous mass of scattered literature upon the subject, and formed it all into a consecutive account, clear and accurate. Discordant statements were weighed and estimated, frequently brought into harmony by an ingenious explanation or by a new and crucial observation. Countless investigations were repeated and verified, and countless suggestions of important work, that still remains to be done, make the book as valuable to the *savant* as to the student. Among the chapters [2] most remarkable for broad and philosophic generalisations are those dealing with the 'Ancestral Form of the Chordata,' 'Larval Forms,' and the 'Origin and Homologies of the Germinal Layers.' Balfour accepts the gastrula as a stage in the evolution of the metazoa, and leans somewhat to invagination, as the more primitive process than delamination in the production of the gastrula. He shows distinctly that the mesoblast arose in the first instance, not independently, but as a differentiation from the other two layers, and that the mesoblast is a homologous structure throughout the triploblastic metazoa. In the chapter on 'Larval Forms' he gives numerous reasons and arguments for a larval development repeating the ancestral history, better and more fully than a fœtal development; he reviews the types of larvæ (discriminating six types), the causes tending to produce secondary changes in larvæ, and suggests, as a hypothesis for the passage from the radial to the bilateral type, that in a pilidium-like larva the oral face elongated unequally, an anterior part forming a præ-oral lobe, and a posterior outgrowth the trunk, while the aboral surface became the dorsal surface. He suggests that adult Echinodermata have retained, and not secondarily acquired, their radial symmetry, and considers a radially symmetrical organism, like a medusa, as the prototype of all the larval forms above the cœlenterates. Balfour does not admit the specially close relationship of the Chordata with the Chætopods, which Dohrn and Semper maintain; but considers that the Chordata descended from a stock of segmented worms derived from the same unsegmented types as the Chætopods, but in which two lateral nerve-cords like those of the nemertines coalesced dorsally instead of ventrally. He considers that the mouth in ancestral Chordata was suctorial, and was not formed, as Dohrn supposes, by the coalescence of two visceral clefts. Finally, Balfour draws up a scheme of the phylogeny of the Chordata, according to which the hypothetical protochordata, with a notochord, a suctorial mouth, and very numerous gill-slits, acquired one by one, vertebræ, jaws, an air-bladder, a pentadactyl limb, an amnion: each new accession characterising a hypothetical proto-group, from which some existing group is supposed to have diverged.

Those of my hearers who had not followed Balfour's scientific labours, but who merely knew him as one of the most respected workers in the field of biology, will I trust, even from my brief sketch, have formed some idea of the activity and originality of his mind, and will understand how his death has occasioned a feeling almost akin to despair, in that he occupied a place which it appears to us now impossible to fill. 'How are the mighty fallen, and the weapons of war perished!'

[1] *Comparative Embryology*, vol. i. 1880, vol. ii. 1881.
[2] Ibid. vol. ii. chaps. xi. xii. xiii.

On the Growth of our Knowledge of the Process of Secretion in the Animal Kingdom.

The Views of the Ancients.

It was known to the ancients that organs of the body exist which are concerned in the separation from it of excrementitious substances, although the greatest doubts prevailed as to the organs to which such functions should be ascribed. Thus we find Hippocrates defining it as characteristic of glands that they occur in moist parts of the body; but showing his ignorance of the true relations of glands to secretion by connecting them with the formation of hairs, and discussing the question which we find our own Wharton debating again in the seventeenth century, and which he formulates, 'Num cerebrum ad glandularum numerum vel viscerum accedat.' The general opinion of the ancients, and the opinion which was adopted and taught by Galen, was that the glands were sieves or collanders (cola), which served to strain off from the blood purely excrementitious substances. The liver and the kidneys were strangely enough removed from the group of glands and placed amongst the viscera. The first writer who appears systematically to have treated of the glands was the before-mentioned Wharton in his 'Adenographia sive glandularum totius corporis descriptio.' Although this author certainly added to the existing knowledge of the descriptive anatomy of secreting organs, his views on the functions of glands were strangely fanciful and erroneous.

The glands he considered to be specially related to the nervous system, the viscera, so-called, to the blood-vessels; such glands as the pancreas, and the salivary and lachrymal glands being engaged in separating excrementitious substances from the nervous system. It was in 1665 that the great anatomist Malpighi[1] first attempted to investigate the structure of glands in a truly scientific spirit, endeavouring to establish a relationship between simple glandular follicles and such complex glands as the liver. All glands he believed to contain as ultimate elements bodies which he termed '*acini*,' a word which in its primitive classical sense had been used to designate the stone or seed of the grape or the grape itself. The conception, indeed, which Malpighi formed of an '*acinus*' was rather that of a secreting nodule than of an ultimate saccular or tubular recess. The '*acini*,' however, he believed to be in communication with the efferent ducts of the glands to which they belonged, and through which they poured out their proper secretion, derived in the first instance from the blood contained in minute arteries supplied to the gland. Ruysch (1696), known as the first celebrated injector of blood-vessels, finding that frequently the fluids which he forced into the blood-vessels of glands escaped through their ducts, or made their way into the surrounding tissues, concluded that the blood-vessels communicated directly with the interior of the glands; these he held to be organs which, according to the views that had long prevailed, merely strained off from the blood certain of its more liquid constituents. The views entertained by the most eminent of the supporters of Ruysch, the illustrious Haller, were expressed by him as follows. After defining the term 'acinus' to signify the ultimate division of a gland, he remarks that 'the acini consist of congeries of vessels, bound firmly together with a cellular web, containing an excretory duct in their interior, which commences from the most minute arteries by small ducts impervious to the blood. . . . So that secretion differs from the ordinary circulation of the blood in this particular, that the smallest arteries are continuous with veins of equal or greater size, capable therefore of receiving the blood, whilst the excretory ducts are much smaller, in order to effect the separation of the secretion.'[2] The advocates of the Ruyschian theory were compelled to have recourse to the most improbable hypotheses to explain the diversity of the secretions of different glands, as for example, that different glands secrete different liquids, because of the difference in the diameters of the pores by which the blood-vessels communicate with the glands; that the different arrangement of blood-

[1] Malpighi, *Exercitatio Anatomica de Renibus.*
[2] Haller, p. 275.

vessels, the mode in which they divide, the resistance which they offer to the flow of blood through them, by modifying the pressure and velocity of the blood-flow through the organ, induce secretions varying in character. It is strange to learn from Haller, as was indubitably the fact, that the great majority of his contemporaries, such men as Peyer and Vieussens, and even Boerhaave, adopted the Ruyschian view of the structure of glands. The opposition to Ruysch came first from Ferrein,[1] who maintained that the kidneys essentially consist of an assemblage of convoluted tubes, which he looked upon to be the seat of the renal secretion—tubes which a subsequent investigator, Schumlansky,[2] looked upon as taking their origin in the acini of Malpighi, to which he referred the active part in secretion. Then followed the researches of Mascagni and Cruickshank, who found, by injecting quicksilver into the mammary glands, that the ramification of the ducts of this organ terminate in racemose follicles; though Mascagni still admitted a connection, by means of open pores, between the sides of the glandular blood-vessels and the interior of the glands themselves. It was unquestionably Professor E. H. Weber, of Leipzig, who completely demolished the Ruyschian hypothesis, and who by numerous researches on the salivary glands of birds and of mammals, and on the pancreas of birds, established the general fact of the termination of gland-ducts in blind extremities, though with modesty he put forward his opinions as confirming the inductions of Malpighi, expressing himself as follows: 'Admirably did Malpighi avail himself of the structure of the liver in the lower animals, and the embryo of the higher, as a foundation-stone for his opinions: for the arrangement of the whole glandular system speaks for itself, inasmuch as it simply consists of single, compact, hollow, blind canals, more or less numerous, floating in the fluid which surrounds their organs; and, although these ramifications are drawn out between the branches of the blood-vessels, there is no immediate passage from one to the other.'

The Researches of Johannes Müller.

Such was the state of knowledge in reference to the structure of secreting glands and secretion at the time when the great Johannes Müller undertook the investigation of which the results were first of all published in the memorable work entitled 'De Glandularum secernentium Structurâ penitiori earumque prima Formatione.'[3] It is impossible not to sympathise with the reflection of Professor Heidenhain, recently made in reviewing the researches of Johannes Müller in connection with this subject;[4] to wit, that the physiologists of to-day may be accused of ingratitude for having allowed the great name of Johannes Müller to have well-nigh disappeared from the pages of physiological literature. We forget that this man—this giant in the field of biology as he is appropriately termed by Heidenhain, the last man of whom perhaps it will ever be said that he was at once the greatest comparative anatomist of his time, and the most philosophical and original of all contemporary physiological writers—by his own researches, and particularly by the one which concerns us to-day, influenced the progress of physiology, at a most critical period, more than any other man. He was not, like his contemporaries Magendie and Flourens, a great physiological experimenter, though he showed that he well appreciated the value of experiment in advancing our science; but he was pre-eminently a physiologist who recognised the immense importance of a close study of structure, not only because of the interest which it presents to the pure and philosophical morphologist, but because of its absolute necessity, if we are to penetrate at all deeply into the secrets of animal function. Müller, in the first instance, had convinced himself, by the study of the circulation of organs sufficiently transparent to permit of it, especially the circulation through

[1] Ferrein, 'Sur la structure des Glandes,' &c. *Mémoires de l'Acad. Roy. des Sciences de Paris*, 1749.

[2] Schumlansky, *Dissertatio Inaugur. Anatomica de Renum structura*, Argentoreti, 1880.

[3] Lips. 1830.

[4] Heidenhain in Hermann's *Handbuch der Physiologie*, vol. v. (1880) p. 6.

the liver of larval salamanders, that, in glands, arteries never end in any other mode than by capillaries leading into veins. He set himself then to study in the case of most glands, and in a large variety of animals, the relationship of gland-ducts to the truly secreting parts of the organ, and the relation of the blood-vessels to these. Basing himself upon these anatomical studies of adult organs, and upon a careful study of the development of glands—a study which had been attempted slightly by Malpighi, and more satisfactorily in the case of the parotid by E. H. Weber [1]—Muller came to the conclusion that all glands possessed of a duct are only involutions more or less complex of membranes, the largest number being involutions of the external investment of the body or of the membranes opening upon its surface. The following are the general results relative to the structure of glands which Müller deduced from the anatomical study of individual organs:— [2]

1. However various the forms of their elementary parts, all secreting glands without exception (not only those of the human body, but all met with in the animal kingdom) follow the same law of conformation, and constitute an uninterrupted series from the simplest follicle to the most complex gland.

2. No line of demarcation can be drawn between the secreting organs of invertebrata and those of vertebrate animals; not merely do we meet with the simplest sacs and tubular secreting organs, like those of insects, in the higher animals, but there is a gradual transition from these simple secreting organs to the glands of the most perfect vertebrata.

3. All glands agree in affording by their interior a large surface for secretion. The varieties of internal surface by which the great end—extent of surface in a small space—is attained, are very numerous.

4. *Acini*, in the hypothetical sense in which the term has been used by writers—in the sense, viz., of secreting granules—do not really exist; there are no glomeruli of blood-vessels with ducts arising from them in a mysterious way, as has been supposed, whatever notions may have been held regarding them.

5. The parts described as *acini* are merely masses formed by the agglomeration of the extremities of the secreting canals; frequently, indeed, they are formed of minute vesicles aggregated together in grape-like bunches, which may be injected with mercury, and are often susceptible of inflation.

6. In many glands which have been incorrectly described to have *acini* or secreting granules, there are not even the hollow vesicular *acini*; the secreting tubes, instead of terminating in vesicles or cells, form long convoluted canals or straight tubuli or short cæca.

7. It has been demonstrated in the case of all glands that the blood-vessels are not continuous with the secreting tubes—that the minute vessels bear the same relation to the coats of the hollow secreting canals, and their closed extremities, as to any other delicate secreting membrane, such as, for example, the mucous membrane of pulmonary air-cells.

8. The arborescent ramifications of the blood-vessels accompany the ducts in their development, and the reticulated capillaries in which the blood-vessels terminate are extended over all the closed elementary parts of the gland and supply them with blood. In the chick we may observe the simultaneous development of the two systems; in proportion as the development of internal surface from a plain membrane to cæcum and ramified cæca proceeds, the vascular layer of the originally simple membrane is raised on the exterior of the efflorescence.

9. The ramified canals and tubes, which when the structure is simple, as in insects and crustacea, and even in some glands of the mammalia, lie free and unconnected, become more aggregated together, and acquire a common covering

[1] E. H. Weber, *Beobachtungen über die Structur einiger conglomerirten und einfachen Drüsen und ihre erste Entwickelung.* Meckel's *Archiv* for 1827, p. 274.

[2] This abstract of Müller's general conclusions has been abbreviated from the sections treating on this subject in his *Elements of Physiology.* See Translation by Dr. Baly, London, 1838, vol. i. p. 456 *et seq.*

in proportion as their evolution is carried further; and thus is produced a parenchyma or solid organ.

10. The capillary blood-vessels are for the most part much more minute than the smallest branches of the ducts of secreting canals and their cæcal extremities, even in the most complex glandular organs. The elementary parts of glands, though minute, are of such a size that the capillary blood-vessels form around them a network which invests them.

11. The formation of the glands in the embryo displays the same progressive evolution from the simple to the complex state as is observed in ascending the animal scale. The most perfect and complex glands of the higher animals, when they first appear in the embryo of these animals, consist merely of the free efferent ducts without any branches, and in that state exactly resemble the secreting organs of the lower animals. The glands are formed from the unbranched tubes by a kind of efflorescence or ramification.

12. The mode in which the extent of internal secreting surface of a gland is realised is very various; and no one kind of conformation is peculiar to any kind of gland. Perfectly different glands may have a similar elementary structure, as is the case, for instance, with the testes and the cortical substance of the kidneys. And similar glands have often a perfectly different structure in different animals; of which the lachrymal glands, examined in the chelonia, birds, and mammalia, afford an example.

Johannes Müller recognised thoroughly, as we have seen, that the character of a secretion cannot be deduced from the structure of the organ which produces it. Was he able to throw any light upon the mystery which had baffled all his predecessors and to explain the cause of the specific endowments of the different glandular organs? Let us allow Müller to speak:—

'The peculiarity of secretions does not depend on the internal conformation of the glands; for, as I have sufficiently demonstrated, each secretion is in different animals the product of the most various glandular structures, and very different fluids are secreted by glands of similar organisation. The nature of the secretion depends therefore solely on the peculiar vital properties of the organic substance which forms the secreting canals, and which may remain the same, however different the conformation of the secreting cavities may be; while it may vary extremely although the form of the canal or ducts remains the same.' It was the living lining substance of the gland which, according to Johannes Müller, formed the secretion, at the expense of materials which it obtained from the blood of contiguous capillaries. This living substance lining the inner recesses of the glands had not yet been differentiated into its constituent units, the secreting cells, and therefore Müller's statement wanted a certain definiteness, though, so far as he went, he was perfectly accurate.

The Researches of John Goodsir.

The success with which that eminent pupil of Johannes Müller, Theodore Schwann, had extended the generalisations of Schleiden (on the part taken by the cell in the formation of vegetable structures) to the elucidation of the animal tissues, had given the greatest impulse to the study of animal histology, and a large number of observers, especially in Germany and England, were directing their attention to the discovery and study, in all tissues and organs, of the all-important cells.

Purkinje had announced the hypothesis that the nucleated epithelium which he discovered to line the gland-ducts might exercise secreting functions. Henle had described with great minuteness the epithelium cells which line the ducts of the principal glands and follicles, and which form the most superficial structures of mucous membrane, and Schwann had suggested that this epithelium probably played a part in the act of secretion. It was, however, unquestionably the Scottish anatomist, John Goodsir, to whom was reserved the merit of establishing in an indisputable manner the fact that the essential and ultimate secreting structures in glands are the morphological units, the gland-cells. As Johannes Müller had examined the arrangements and coarser structure of glands throughout the animal

kingdom, with the result of discovering the general plan of gland-structure, and the analogies existing between glands, however diverse, so John Goodsir passed under review the histological characters of the cells of different glands in a large variety of animals, vertebrate and invertebrate. His first results were published in the 'Transactions of the Royal Society of Edinburgh' for the year 1842; his more matured views were developed in a paper entitled 'On Secreting Structures,' which formed one of a collection of papers which saw the light in 1845. As a result of his survey Goodsir came to conclusions of which the most important may be stated, almost in his own words, as follows:—

'The ultimate secreting structure is the primitive cell endowed with a peculiar organic agency, according to the secretion it is destined to produce. I shall henceforward name it the primary secreting cell.

'Each primary secreting cell is endowed with its own peculiar property, according to the organ in which it is situated. In the liver it secretes bile, in the mamma milk, &c.

'The primary secreting cells of some glands have merely to separate, from the nutritive medium, a greater or less number of matters already existing in it. Other primary secreting cells are endowed with the more exalted property of elaborating, from the nutritive medium, matters which do not exist in it.

'The discovery of the secreting agency of the primitive cell does not remove the principal mystery in which the function has always been involved. One cell secretes bile, another milk; yet the one cell does not differ more in structure from the other, than the lining membrane of the duct of one gland from the lining membrane of the duct of another. The general fact, however, that the primitive cell is the ultimate secreting structure, is of great value in physiological science, inasmuch as it connects secretion with growth, as phenomena regulated by the same laws.'

Goodsir was unquestionably wrong in certain of his speculations concerning secreting cells; as, for instance, in attributing at one time the chief part in the process of secretion to the cell-wall, and at a later period ascribing the same function to the cell-nucleus. He certainly had not grasped the modern idea, which, as I shall afterwards more particularly point out, considers the act of secretion as one of the results of the activity of the living protoplasm of the cell. His assumption, too, that the secreting cell invariably contains, preformed, the characteristic matters of the secretion, is one which is by no means generally true. Nevertheless, it is impossible to study Goodsir's researches on the secreting cell, without ascribing to him the merit of having been the one who made the most important generalisation, connecting cell life with a definite organic function.

I may be permitted, as it were parenthetically, to refer for a moment to John Goodsir, with the veneration which is natural in one who was his pupil. If it be true that the rapid march of scientific discovery has caused us well-nigh to forget the great debts which we owe to Johannes Müller, it is no less true that John Goodsir's name has passed into premature and undeserved oblivion. Goodsir's was a mind which in some respects, especially in its tastes, resembled that of Müller. He was a devoted anatomist, and studied morphology in the first instance for its own sake, but also because of the light which it sheds on organic function. He had a powerful intellect, an insatiable thirst for knowledge, a sympathy with all branches of inquiry which could throw light upon the science to which he devoted his life, and a devout and reverential spirit, which was not the less strong because it only rarely found audible, though then it was emphatic, utterance. In the earlier part of his scientific career, numerous papers, for the most part short, but characterised by remarkable originality of observation and freshness of thought, seemed to promise that Goodsir would be one of the most productive of the workers of his time. A lingering illness which, without altogether disabling him, enfeebled his physical powers, and cast a gloom upon a life which had promised so much, almost put an end to his career, in so far as the scientific world at large was concerned, and henceforward he devoted his remaining energies to studies of which the results were for the most part not published, but especially to the task of teaching. Goodsir was a master who, if judged of by the low standard of fitness to instruct the great

majority of his pupils in such a manner as to enable them successfully to pass examinations, would occupy no exalted position. He possessed, however, the far rarer power of instilling into the minds of the best of his pupils that love of original inquiry, and that deep regard for truth, which are the chief incentives to all scientific research of any real value.

The Investigations and Theories of Bowman.

At the time when Goodsir was engaged in his investigations and speculations relating to cells, Mr. Bowman was making researches which were to give him a lasting place among the great histologists of the century.

His investigation on the structure of the kidney,[1] which was published in the 'Philosophical Transactions' for the year 1842, surpassed in completeness as an anatomical study, no less than by the deep insight into the nature of the function discharged by the organ, any investigation of like kind which had preceded it. It not only led to a more complete knowledge of the structure of the kidney than was possessed of that of any other gland, but to far-seeing generalisations concerning the structure of mucous membranes, and of secreting organs generally, which found expression in a masterly article on mucous membranes, published in the year 1847, in the 'Cyclopædia of Anatomy and Physiology.'

Time will not permit of my giving a complete analysis of the (to use a German expression) epoch-making research upon the kidney; but let me remind you that it led to a complete understanding of the relations of the Malpighian bodies to the urinary tubules; to a description which, so far as it went, was perfectly accurate of the tubules themselves, though the scheme upon which these tubes are arranged has, since Bowman's time—thanks to the labour of Henle, Ludwig, and Schweigger-Seidel—been proved to be more complicated than he had imagined; and to a knowledge of the distribution of blood-vessels, not only in the kidney of man and other mammalia, but also in that of certain reptiles.

His study of the structure of the tubuli uriniferi had led Mr. Bowman to discover that in these, a layer of epithelial cells lies upon a structureless membrane, to which he gave the name of the *basement membrane*,[2] and which intervenes between the epithelium and the blood capillaries, whence the materials of secretion are primarily derived. His examination of the mucous membranes of the body led Bowman to the conclusion that the relationship so easily observed in the case of the kidney between cells, basement membrane, and blood-vessels is one which holds true, not only in the case of that organ, but in that of many other epitheliated structures.

'In the mucous tissue,' said Mr. Bowman,[3] 'there are two structures which require to be separately described, viz. *the basement membrane* and *the epithelium*. The basement membrane is a simple homogeneous expansion, transparent, colourless, and of extreme tenuity, situated on its parenchymal surface and giving it shape and strength. This serves as a foundation on which the epithelium rests. The epithelium is a pavement composed of nucleated particles adhering together, and of various size, form, and number. The following general observations on these elementary parts will receive illustration as we advance. Neither the one nor the other is peculiar to the mucous tissue in the sense either of being invariably present in it, or of not being found elsewhere. There are certain situations of the mucous system where no basement membrane can be detected, and others from which the epithelium is absent. Both, however, are never absent together. Again, a structure apparently identical with the basement membrane is met with in numerous textures besides the mucous, and all internal cavities, whether serous, synovial, or vascular,

[1] W. Bowman, 'On the Structure and Use of the Malpighian Bodies of the Kidney, with Observations on the Circulation through that Gland,' *Philosophical Transactions* for the year 1842, Part I. p. 57.

[2] *Op. cit.* p. 58.

[3] Article 'Mucous Membrane,' in *Todd's Cyclopædia*, p. 436.

or of anomalous kind (as those of the thymus and thyroid body), are lined with an epithelium.'

As a result of his anatomical studies on the kidney, Mr. Bowman was led to frame a theory of renal secretion, which, though opposed for a time by a master mind, has, by the progress of research, received complete confirmation, and which was based in no small degree upon the new views of the function of epithelial cells in glands. The Malpighian body, Bowman showed, is the dilated commencement of a convoluted tubule, and, like it, presents a delicate, structureless, basement membrane. Into the Malpighian body projects a tuft of capillary vessels, continuous, on the one hand, with an afferent vessel derived from a branch of the renal artery, on the other, with an efferent vessel of smaller size than the afferent; both afferent and efferent vessels piercing the capsule of the Malpighian body; after leaving the glomerulus, the efferent vessel breaks up into a series of capillaries, which are distributed to the walls of the convoluted tubes. The tuft of blood-vessels projecting into the Malpighian body, Bowman described as being perfectly bare, that is to say, not covered by a basement membrane, or by a layer of epithelium cells. This part of his description has not been confirmed by recent work, the more delicate methods of modern histology allowing of a ready demonstration of a layer of cells of extreme tenuity covering the glomerulus.

The basement membrane of the convoluted tube was described as lined by a nucleated epithelium of a finely granular opaque aspect; the neck of the tube, where it joins the Malpighian capsule, and the contiguous portions of the capsule were described as covered by a layer of cells, differing altogether from the first, being much more transparent, and possessing in certain animals vibratile cilia. In some cases the whole interior of the capsule was lined by epithelium cells of great delicacy and tenuity; in others, these cells could not be traced over more than a third of the capsule. Basing himself upon the altogether exceptional arrangement of the blood-vessels of the glomerulus, Bowman advanced the theory that this is a structure destined to separate from the blood its watery portion. The epithelium of the convoluted tubes, on the other hand, which Bowman pointed out to be 'eminently allied to the best marked examples of glandular epithelium,' he believed to be concerned in the separation of the characteristic solid matters of the renal secretion.

I shall for the present conclude my remarks upon Mr. Bowman's investigations and theoretical views by stating that, by his investigations of the blood-supply to the kidney of the boa constrictor, he gave the strongest proof which could be derived from anatomical evidence of the correctness of his views, and furnished great part of the knowledge required for the subsequent researches which Nussbaum made on the secretion of the newt's kidney, and which afforded the most conclusive experimental evidence in favour of the theory which Bowman had advanced.

The Discoveries of Carl Ludwig.

If to Johannes Müller we must ascribe the greatest share of merit as a discoverer of the general affinities, relationships, and functions of glands, it appears unquestionable that to Carl Ludwig belongs the credit of having, above all others, brought the light of experimental physiology to bear upon the subject of secretion.

Ludwig is one of the most eminent of the physiologists who have endeavoured, so far as possible, to apply the conceptions derived from a study of physical and chemical processes in general, to the elucidation of the functions of the organism. More than anyone else has he successfully adapted the methods of research of the chemist and of the physicist to the investigation of the problems which lay before him. Above all others he is to be spoken of as the great teacher amongst all of the great teachers of physiology which this century has produced. If we try to find one who, from the fertility of his mind and the influence which he had upon men of ability, affected the progress of his science in like measure to Ludwig, we revert to the name of Liebig. When I say that physiology owes as much to Ludwig as chemistry to Liebig, I shall, I feel sure, be doing but scant justice to

the great man, who at Marburg, at Vienna, and at Leipzig, has won for himself the right to be called at once the greatest physiologist, and the greatest teacher of physiology, of his time.

1. *Ludwig's Discovery of Secreting Nerves.*

It was in the year 1851 that Ludwig first announced to the scientific world [1] the fact that the secretion of the salivary glands is under the influence of the nervous system. C. G. Mitscherlich, as Ludwig points out, had surmised that the secretion of saliva only occurs as the result of a stimulation of certain nerves, *i.e.* the nerves of taste and the nerves supplying the muscles of mastication. No attempt had, however, been made, before Ludwig's, to ascertain experimentally whether the stimulation of nerves supplying glands influenced directly their secretion. As a subject of study Ludwig chose the submaxillary gland. He found that on stimulating by a succession of induction shocks the nerve-twigs proceeding from the lingual branch of the fifth nerve, and which accompany Wharton's duct to the gland, secretion of saliva occurred, so long as the excitability of the nerves persisted.

In experiments performed in conjunction with his pupil Rahn, Ludwig found that secretion occurs on direct stimulation of the glandular nerves, even when the circulation has been arrested for a time, as, for instance, when the contractions of the heart are inhibited for some time.

2. *Ludwig's Discovery that Secretion is not a Process directly dependent upon the Arterial Pressure.*

In the paper which I have already quoted, Ludwig published the results of the following experiments. A mercurial gauge was placed in communication with the duct of the submaxillary gland, the height of the mercury in the gauge being recorded (by means of a float to which was attached a writing point) upon the travelling surface of the kymographion, the instrument which Ludwig had contrived for permanently recording the amount and variations of the blood-pressure in arteries and veins. At the same time, another gauge placed in communication with the carotid artery, or one of its branches in close proximity to the gland, recorded the height of the blood-pressure on the same travelling surface. On stimulating the secretory nerves, Ludwig found that saliva was poured out long after the pressure exerted by it upon the interior of the gland (as measured by the height to which the mercury was raised in the gland-duct manometer) exceeded the pressure of blood in the arteries. Thus in his first recorded experiment the mean pressure of blood in the carotid artery amounted to 108·5 millimetres of mercury, whilst during a stimulation of the nerve-filaments going to the gland, the pressure in the gland-duct manometer rose to between 190·7 and 196·5 millimetres, *i.e.* indicated that the pressure exerted by the fluid, secreted under the influence of nerve-stimulation, exceeded the arterial pressure by an amount corresponding to a column of mercury about $3\frac{1}{2}$ inches high. It is obvious that the experiment at once and conclusively proved that the secretion of a watery liquid like the saliva may be brought about by a process altogether different from a process of filtration; for in filtration the passage of liquid through the minute pores of the filter necessarily depends upon a difference in pressure on the two sides of the filter, the movement of liquid being from the side of greater to that of less pressure.

In this brief sketch I have only time to refer to the most salient of the early discoveries of Ludwig on secretion, and must pass over without comment the first experiments by which he showed the influence exerted by variations in the strength of the stimulus of a secretory nerve upon the amount and chemical composition of the secreted liquid.

[1] Ludwig, 'Neue Versuche über die Beihilfe der Nerven zur Speichelabsonderung,' Henle & Pfeifer's *Zeitschrift*, New Ser., vol. i. (1851), p. 255.

3. *Ludwig's Discovery that during Secretion Heat is evolved in Glands.*

Pursuing his researches on the salivary glands, Ludwig some years later,[1] in conjunction with his pupil Spiess, discovered that, when a gland is thrown into action by stimulation of its nerves, heat is evolved. In the case of the submaxillary gland, for instance, he found that the saliva which was secreted might have a temperature nearly three degrees Fahr. (1·5° C.) above that of the blood going to the gland. Important as was this result, because of the light which it threw upon the source of animal heat, its value as bearing upon the nature of the process of secretion was even greater. From the fact that the saliva is a liquid containing but three or four or five parts of solid matters to one thousand of water, it would scarcely have been surmised, upon a merely physical hypothesis, that its production would have been attended by any considerable evolution of heat. The evolution of heat is indeed one of the strongest proofs we have that the act of secretion is the result of the living activity of those ultimate units of the glands, the gland-cells; but to this I shall revert hereafter.

THE RESEARCHES OF SCHIFF, ECKHARDT, AND CLAUDE BERNARD, ON THE SECRETORY NERVES OF THE SALIVARY GLANDS.

The study of the innervation of the salivary glands which had been commenced by Ludwig and Rahn was continued with great success by other observers, and particularly by Claude Bernard and Eckhardt. The first of these observers proved the correctness of Schiff's supposition that the abundant secretion which followed the stimulation of fibres of the fifth cranial nerve was in reality due to the presence of fibres of the chorda tympani mixed with them. It was Eckhardt, however, and afterwards Claude Bernard, who established the remarkable fact that, in the case of the submaxillary gland, and, as has since been shown, of some other glands also, the gland is under the direct control of two orders of nerve-fibres. The first are contained in branches of cranial nerves, and in the case of the submaxillary gland are derived from the facial nerve, and, when stimulated, lead to an abundant secretion of watery saliva, relatively rich in saline and poor in organic constituents; the second are contained in the so-called sympathetic nerve-trunks distributed to the gland; and these, when stimulated, occasion an exceedingly scanty flow of very concentrated and highly viscid saliva, containing a relatively large quantity of organic constituents, particularly of mucin.

Claude Bernard now pointed out that stimulation of the above-mentioned nerves leads to changes in the circulation of blood through the gland, in addition to the changes in the amount and quality of the fluid secreted by it.

Thus stimulation of the cerebral fibres supplying the chorda tympani was found to produce a great dilatation of the arteries of the gland; so that the amount of blood passing through it was very largely increased, that passing out through the venous trunks of the gland presenting a florid arterial colour instead of the brown venous hue observed when the gland was not secreting. Stimulation of the sympathetic fibres, on the other hand, caused a great contraction of the glandular arteries, consequently a diminution of the flow of blood through the gland and into the veins, the blood presenting under these circumstances an intensely venous hue.

The facts just referred to appeared reconcilable at first with the view that the secretion of saliva, as a result of nerve-stimulation, was primarily dependent upon changes in the circulation of blood through the gland; though, upon reflection, the surmise was negatived by some of the facts discovered long before by Ludwig, and particularly by that, already referred to, of glandular secretion following stimulation of glandular nerves, even where the circulation has been stopped, as by cardiac inhibition.

Bernard's experiments had unquestionably established that in addition to nerves which, when stimulated, occasioned the contraction of arteries—'the vaso-motor' or, as we now sometimes call them, the 'vaso-constrictor' nerves—there

[1] Ludwig u. Spiess, *Sitzungsber. d. Wiener Akad.* Mathem. u. Naturwissenschaft: Class, vol. xxv. (1857), p. 548.

are others which when stimulated occasion, on the contrary, the dilatation of arteries—the so-called 'vaso-inhibitory' or 'vaso-dilator' nerves. That it was not stimulation of the vaso-dilator nerves, which, by increasing the amount and the pressure of the blood flowing through the capillaries, occasioned the secretion of saliva, was shown by several experiments, but especially by an observation of Keuchel. This observer found that the alkaloid of the deadly nightshade, viz. atropia, when introduced into the system, exerts such an action, that on stimulating the chorda tympani no secretion of saliva follows; whilst, on the other hand, dilatation of the arteries is produced exactly as under normal circumstances. Other drugs have since been discovered which exert a similar action to that of atropia in paralysing secretory nerves, whilst some are now known which antagonise the action of atropia, and restore the suspended activity of the secretory nerves. From these studies has unquestionably resulted a knowledge of the conclusion, that although the process of secretion is favourably influenced by the vascular dilatation which follows the state of activity of the vaso-dilator nerves, the actual process of secretion is not due to them, but, so far as it is controlled by the nervous system, is directly under the influence of certain nerves which may be termed secretory.

Discoveries which show that Secretion, though influenced by, is not necessarily dependent upon, Stimulation of Nerves going to a Gland.

A knowledge of the facts which I have brought before you hitherto would of itself lead you to suppose that glandular secretion is a process which is in abeyance except under the influence of stimulation of nerves which throw the gland into activity, in the same manner as the quiescent muscle passes into activity normally, only when its motor nerves are stimulated. But this supposition, though it may be in some measure true in the case of certain glands, is not borne out by a study of secreting glands in general—a study which teaches us that whilst the activity of the gland-cells may be, and often is, remarkably under the control of the nervous system, it is by no means necessarily dependent upon it. The activity of the gland depends upon the activity of its individual units, the gland-cells; and these units may discharge their function so long as they continue to live and are supplied with the nutriment—mineral, organic, and gaseous—which they require.

Leaving aside, at least for the present, any reference to the arguments which may be derived, by analogy, from a study of cell life in general, I would call your attention to the physiological facts which prove the truth of the proposition just enunciated. The first of these facts was discovered by Claude Bernard: to wit, that when all the nerves supplying the salivary glands are divided, there is at first a temporary cessation of secretion, soon followed, however, by an abundant flow of very watery, so-called paralytic saliva.

This result is fully confirmed by similar observations made in the case of other secreting organs, and which establish very fully the greater or less independence of the secreting elements from the control of the nervous system; though unquestionably, in a normal state of the organism of higher animals, the nervous system is continually intervening, both directly by its influence on gland-cells, and indirectly by the changes which it produces in the circulation, so as to control the operations of gland-cells, and especially to bring them into relation with, and subordinate them to, the work of complex processes of the organism.

What the exact relations of nerve-fibres to gland-cells may be is yet a matter involved in great doubt. The discovery made by Pflüger of the terminations of nerve-fibres in the secreting cells of the salivary glands has not been confirmed by any observers in any vertebrate. Kupffer has, however, unquestionably done so in the case of *Blatta orientalis*, and although as yet objective proof is wanting, we cannot entertain any reasonable doubts that a connection between the ultimate fibrillæ of nerves and secreting cells actually exists. We feel confident that physical, as it were accidental, difficulties have alone hindered the precise determination of the fact.

The Immediate Source of the Nutriment consumed by the Gland-cell.

In the original scheme of a secreting gland, developed first of all by Bowman, then adopted by Goodsir, Carpenter,[1] and many other writers, the essential structural elements taken into account were the following:—1. Epithelial cells lining the secreting cavity of the gland; 2. Sub-epithelial tissue, usually presenting superficially the form of a basement membrane, upon which the cells were placed; and 3. A capillary network in closer relation to the basement membrane, or more superficial part of the sub-epithelial tissue. In harmony with this scheme, the glandular elements were always spoken of as drawing their supply from the blood in the capillaries. The one element which was wanting in that scheme, and which we are able to fit into it, thanks again to the labours of the great physiologist of Leipzig, is the relation of so-called lymph-spaces to the other elements. As was first shown by the researches of Ludwig and his school, amongst the modes of origin of the peripheral lymphatics, the most numerous are to be found in connective tissue, and nowhere more abundantly than in the connective tissue of glands, which is everywhere interpenetrated by irregular spaces containing lymph, from whence spring the minutest lymphatics. If we consider, then, the immediate environment of the secreting cell, we find that in close proximity to it is the lymph, which is a transudation from the blood, and upon which the gland-cells are directly dependent for all the matters which they require. For a certain time, then, the gland-cell will be independent of the supply of blood, that is, so long as the lymph surrounding it contains a sufficient quantity of essential matters, of which oxygen is one of the chief, to support its life, or until it becomes so charged with waste products derived from cell life, *e.g.* CO_2, as to interfere with the functions of the latter. It certainly appears that, at least in the majority of cases, it is the secreting cell which modifies, in the first instance, the composition of the lymph which bathes the tissues in proximity to it, rather than the composition of the lymph which modifies the activity of the gland-cell. There are some cases nevertheless in which it would appear that the presence of certain constituents in the lymph is the direct cause of the activity or increased activity of the cells.

Secreting Cells present different Appearances, corresponding to different States of Functional Activity. The Researches of Heidenhain.

Amongst the physiologists of Europe who have most enriched science by their researches during the last thirty years is unquestionably Professor Heidenhain of Breslau, who has exhibited his mastery of the physical side of physiology by his classical research on the relations between the heat evolved in and the work done by muscle, and as a biologist able to use in the best manner all the resources of modern histology in the elucidation of bodily function, by the researches to which I wish to direct your attention for a few moments.

The glands imbedded in, or the ducts of which open upon the surface of the mucous membrane of, the alimentary canal, for the most part, are characterised by periods of more or less complete cessation of activity, as judged by the diminution, or absolute cessation, of the secretion which they prepare. This is true of the salivary glands and of the liver, but particularly true of the gastric glands and the pancreas.

Certain of these glands, *i.e.* the salivary glands in some animals, and the stomach and pancreas in all in which they exist, have the task of preparing juices which contain certain so-called unformed or unorganised ferments or *enzymes*, upon which the properties of the secretions in great measure depend. Heidenhain in a long series of investigations, which have been taken part in by certain other scientific men, as by Ebstein and Grützner, by Kühne and Lea, and particularly by Mr. Langley of Trinity College, Cambridge, has shown that the secreting cells of a particular gland, as for instance of the submaxillary gland, of the gastric glands, and

[1] Carpenter, in his admirable article on 'Secretion' in *Todd's Cyclopædia of Anatomy and Physiology.*

of the pancreas, exhibit differences in size, differences in the form and appearance of the nucleus, and differences in the cell contents, corresponding to varied states of functional activity.

Time will not permit my mentioning in detail the results of these observations from which, however, certain general conclusions appear derivable. Thus, a gland-cell at rest is usually larger than a similar cell which has been engaged in the process of secretion; from its behaviour to reagents, it usually appears to contain within itself an abundant store of the body or bodies which are chiefly characteristic of the secretion, or closely related antecedents of these, and the amount of undifferentiated protoplasm surrounding the nucleus appears to be at a minimum. On the other hand, the gland-cells, which have been secreting for a greater or less period, often, though not invariably, present a diminution in their size, a diminution in the amount of the characteristic bodies previously referred to, and an increase in the protoplasmic constituents of the cell. All facts, histological as well as physiological, seem to point to the following conclusion: that during rest, the cell forms, at the expense of, or as the product of the differentiation of, the cell protoplasm, the bodies characteristic of the secretion; that whilst secretion is going on these leave the gland-cell; and that, at the same time, the protoplasmic constituents of the latter increase at the expense of the lymph, to be converted secondarily, either at a later period in that particular act of secretion, or in the succeeding period of inactivity, into specific constituents. The researches of Heidenhain have been conducted upon the glands after these had undergone processes of hardening and staining, the appearances observed indicating changes which, though not identical with, at least corresponded to various conditions of the gland. Kühne and Lea and Langley have, however, studied glands in a living condition, and though the appearances were not identical with those observed by Heidenhain, they entirely confirm these.

I have not time to do more than refer to the fact that in some at least, though probably in all of the cells of glands which produce secretions containing ferments, there are formed at first bodies to which the generic term of '*zymogens*' may be applied, i.e. *ferment-generators,* from which a ferment is afterwards set free.

In connection with this part of my subject I may refer to the view, which was at one time held by some, that in secreting glands the gland-cell, having produced the matter of the secretion was thrown off, discharging its contents into the secretion. This process, when it does occur, must be looked upon as exceptional, and as it were accidental.

Amongst the most striking examples of the success with which physiological experiment and subsequent histological research have been pursued in combination so as to throw light upon the functions of particular cells, I may refer first to the observations of Heidenhain, secondly to those of Nussbaum on the excretion of colouring matters, artificially introduced into the blood, by the secreting epithelium cells of the renal tubules. I have previously referred to the theory of Bowman, according to which the watery and saline constituents of the renal secretion were supposed to be separated by the so-called '*glomeruli,*' whilst the organic solids of the secretion were supposed to be separated by the epithelium lining the convoluted tubes.

To this theory was opposed that of Ludwig, according to which the whole of the constituents, watery, saline, and organic, were supposed to be poured out of the vessels of the glomerulus, the amount of water however being far in excess of that contained in the liquids when it reaches the pelvis of the kidney. Ludwig supposed that as the secretion passed over the surface of the epithelium lining the complex tubules, processes of diffusion occurred between it, on the one hand, and the lymph bathing the tissues lying outside of the basement membrane of the tubules on the other, the direction of the current of water being from without inwards. The anatomical evidence adduced by Bowman was of itself well-nigh sufficient to prove the accuracy of his views, which have however been placed beyond all dispute by the following observations: Heidenhain introduced into the blood a solution of sulphindigotate of sodium, usually some time after having divided the spinal cord in the cervical region. On killing the animal some time afterwards and subjecting the kidney to careful examination, it was found that the

colouring matter had been accumulated by the epithelium of the convoluted tubules from the lymph bathing the tissues, and which contained so little colouring matter as to appear colourless. If a sufficient time had elapsed after the injection, the colouring matter was found in the form of granules or minute crystals lying on the inner side of the cell in the lumen of the tubules.

Bowman, as I have already mentioned, had in the case of the boa constrictor studied in detail the blood-supply to the organ, which, as Jacobson had shown, differs in fishes, birds, and reptiles from the mode of arrangement prevailing in mammals.

Bowman had shown that in the boa the glomeruli derived their blood exclusively from the renal artery, and the convoluted tubes exclusively from the common iliac vein. Nussbaum gave absolute completeness to the proof of Bowman's theory by the following remarkable experiment. Experimenting on the newt, in which the blood-supply of the kidney is similar to that of the boa, he found that, when he tied the renal artery, he arrested almost entirely the secretion of water in the kidney, but that the excretion of urea and other solid matters, and amongst others of the colouring matter already used by Heidenhain, viz. indigo carmine, continued. Ligature of the renal branches of the common iliac vein stopped the secretion of organic solids without impeding that of water.

The most recent Theories advanced in Explanation of the Phenomena of Glandular Secretion.

Having brought before you the most salient facts with which we are acquainted, which appear to throw the most light upon the general physiology of glandular secretion, I wish, before concluding, to speak of the theoretical views which have been advanced in explanation of a large number of the facts.

In the first place, I have to confess that our ignorance is absolute as to the cause of the specific endowment of different secreting cells, in virtue of which they produce new bodies at the expense of certain of the materials supplied to them by the lymph, or separate particular constituents from the lymph, to the exclusion of others which are equally abundant in the liquid. We express the full measure of our ignorance when we state that the difference in function of different gland-cells is due to differences in endowment of the protoplasm of the cell, which in no case is explained by any objective characters of the cell.

The phenomena of the secretion of water, which forms so large a part of every secretion, have given rise, however, to numerous speculations, concerning which I may make a few remarks.

The primitive view that the glands are organs in which is strained off from the blood water holding certain substances in solution has, in a modified manner, found favour with some even to our own days, and appears indeed, at first sight, to be borne out by certain facts. Thus within wide limits the amount of water secreted by the kidney depends upon the pressure of blood in the glomeruli. Any circumstances which will lead to an increase of pressure in these vessels (as increase of blood-pressure generally, division of renal nerves, division of the splanchnics, especially when combined with stimulation of the spinal cord), by dilating the branches of the renal artery, will lead to this result. At first this would seem to show that the process of separation of water, in the kidney at least, is but a process of filtration, though a remembrance of the famous experiment of Ludwig, referred to at an earlier period, on the relation between the pressure of secretion of saliva and that of the blood in the arteries, would impose caution in drawing the conclusion. What are the facts, then, relating to the blood-pressure in vessels in other organs of the body, and the transudation of liquid from them?

If an increased arterial pressure led *ipso facto* to an increased transudation through the capillary walls, it would follow that the amount of lymph and the pressure of the lymph-stream would rise with the rise of the arterial pressure, but direct experiments on this matter have led to an opposite conclusion. The experiments of Paschutin and Emminghaus, carried out under Ludwig's direction, have shown that when the arterial pressure in the extremities is increased, there is no

corresponding increase in the lymph produced. Again, when the chorda tympani is stimulated in an animal into whose blood atropia has been introduced, the vascular dilatation which is produced, and which is then unaccompanied by secretion, does not lead to an increased production of lymph, which would make itself evident by the gland becoming œdematous. How then are we to account for the flow of water through a gland? By ascribing it to an influence which is exerted by the gland-cell, in the first place, upon the liquid which environs it, viz. the lymph. And accordingly, even in the case of the glomeruli of the kidney, we conclude that the water is separated as a direct result of the activity of the layer of transparent epithelium cells which cover them. Hering has advanced a strictly physical theory, which would account for the mode in which certain cells exert this influence, by supposing that there is produced within them bodies which, like mucin, have a great affinity for water and which then pass into the secretion; and which therefore lead to a current of water passing through the cell; but the theory is one which cannot be admitted, because, as Heidenhain points out, the passage of water through a gland occurs in cases where there is no constituent in the cells at all resembling mucin in its affinities or behaviour towards water.

I feel inclined to say that the speculations, necessarily indefinite though they are, of Professor Heidenhain afford the best explanation of the phenomena. Heidenhain starts from the fundamental fact that during secretion only as much water passes out of the blood-vessels of the gland as appears in its secretion, seeing that, however long the process of secretion may continue, the gland never becomes œdematous, nor does the current of lymph from it increase.

The volume of liquid filtered through the blood-capillaries adjusts itself exactly to the volume of liquid separated by the cells. This equality in the amount of liquid secreted and filtered appears only explicable on the supposition that the act of secretion is the cause of the current of water—in other words, that the water which the cells lose in the formation of the secretion generates changes in them which can only be compensated for by an abstraction of water from the immediate environment.

Within certain limits, Heidenhain continues, we may form purely physical conceptions of the process. We may conceive, for instance, the whole protoplasm of the cell to have a certain affinity for water. The cells at their contact with the basement membrane may be supposed to be able to abstract water from it; the loss which the membrane sustains will be made up by the lymph, and this again will influence the blood in the capillaries.

The passage of water into the cells will go on until a period of equilibrium is attained; but at that time the current of water from the capillaries through the lymph to the cells will cease. We may conceive further, reasons Heidenhain, that the passage of water out of the cell is hindered by such obstacles to the process of filtration as are represented by resistance opposed to it by the superficial border layer of protoplasm. If we now conceive that—for example, as a result of nerve-stimulation—the gland-cells pour out water, the condition of equilibrium which existed between cell, basement membrane, lymph, and capillary will be disturbed, and a current of liquid set in from the last to the first, and continue as long as the activity of the cells continues.

It is not difficult moreover, Heidenhain remarks, to form physical conceptions of the processes whereby water may be separated from the cell itself. It is conceivable, for instance, that the protoplasm of the cell may contract after the manner which occurs in many infusoria, and which in them leads to the accumulation of water in droplets, forming vacuoles, except that in the case of the secreting cells the water is poured out on the outside and not on the inside of the cells. Or, again, it is possible that on the gland-cell passing into the condition of activity an increased production of CO_2 may occur, leading to an increased diffusion of water outwards.

So far, I have quoted Professor Heidenhain, for the most part in his own words. Let me add, however, that the two hypotheses which he advances as possible explanations of the mechanism of secretion of water by the cell rest upon the most probable grounds, as upon the presence of the intra-cellular protoplasmic

network which has been so beautifully demonstrated by recent researches, and especially by those of Professor Klein; or, again, upon the fact, proved by the analyses of Professor Pflüger of the gases of the saliva, that there is during secretion great production of CO_2, as shown by the amount of this gas in the saliva being much greater than in the blood, and upon the fact of the remarkable diffusibility of acid solutions.

Reasoning upon a large number of facts, which I have not time to refer to, Professor Heidenhain has come to the conclusion that, quite apart from the nerves which control the vascular supply to a gland, there exist two distinct sets of nerve-fibres in relation to the glandular elements. The first of these, which he terms 'secretory,' when stimulated, lead to the secretion of water and saline constituents; the second, which he terms 'trophic,' influence the transformations of the protoplasm of the cell, and thus affect the organic constituents of the secretion.

I do not wish to pronounce a definite opinion concerning this hypothesis, but would remark that the nomenclature proposed by Heidenhain appears to me to be an unfortunate one, especially because it attaches a new meaning to a word which had previously been used by physiologists in a different sense. I refer to the adjective *trophic*, which has always implied 'governing nutrition.' It appears to me almost inconceivable that if there exist two sets of secretory nerves, the action of each should not profoundly affect the nutrition of the cell protoplasm, though, of course, it is conceivable that they should do so in very different manners.

General Conclusions.

The complicated studies, of which I have attempted to give you a brief sketch, have led to our forming certain clear general conceptions in reference to the process of secretion. They have brought into greater prominence the dignity, if I may use the expression, of the individual cell. The process of secretion appears as the result of the combined work of a large number of these units. Each, after the manner of an independent organism, uses oxygen, forms CO_2, evolves heat, and derives its nutriment from the medium in which it lives, and performs chemical operations of which the results only are imperfectly known to us, and which depend upon peculiar endowments of the cell protoplasm, of which the causes are hidden from us. So long as the protoplasm is living, the gland-cell retains its power of discharging its functions, and in many cases does so, so long as the intercellular liquid furnishes it with the materials required. In some cases, however, the gland-cells are specially sensitive to a variation in the composition of the nutrient liquid, certain constituents of which appear to stimulate the protoplasm to increased activity. In the higher animals the cells, particularly in certain glands, are in relation to nerves which, when stimulated, affect in a remarkable manner the transformations of their protoplasm, leading to an increased consumption of oxygen, an increased production of carbonic acid, an increased evolution of heat, and an increased production of those matters which the cell eliminates and which constitute its secretion.

This historical survey of the growth of our knowledge of the process of secretion exhibits the characteristic features of biological advancement. Comparative anatomy has been the foundation of, observation of facts and physical experiment the road to, physiological research. At various stages the value of hypotheses has been well illustrated, and, whenever they have had to make way for the broader and truer interpretations suggested by the accumulation of facts and greater precision of observation, it has been demonstrated that the process of observation is not one of simple sight but of complex ratiocination.

FRIDAY, AUGUST 25.

The following Report and Papers were read:—

1. *Report on the Influence of Bodily Exercise on the Elimination of Nitrogen.* See Reports, p. 269.

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2. *On the Early Development of certain Rodents.* *By* Dr. Alex. Fraser.

The author announced, as a preliminary communication, his having ascertained the fact of the existence in the rat and mouse of an inversion of the layers of the blastoderm, the same as in the guinea-pig. He also described some of his observations, and exhibited microscopic specimens illustrating them.

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3. *On the Homologies of the Long Flexor Muscles of the Feet of Mammalia.*[1] *By* G. E. Dobson, *M.A.*, *M.B.*

The muscles, with the homologies of which this paper deals, are as follows:—
1. *Flexor digitorum fibularis* = *Flexor hallucis longus* (Human Anat.).
2. *Flexor digitorum tibialis* = *Flexor digitorum longus* (do.).
3. *Tibialis posticus.*

The various modifications of these muscles in many species of the different orders of mammalia were described, the leading ones being illustrated by enlarged drawings of the dissected limbs. Examination of a large series of specimens showed that the three muscles are represented by their homologues in most mammals, the *flexor fibularis* existing in all, and exhibiting but few modifications, while the other two are subject to much variability, and in some instances are severally or collectively absent. Of these the *flexor tibialis* was found to vary very considerably within certain limits, a variability hitherto not understood by anatomists, and attempted to be explained by supposing the muscle to have undergone fusion with the *flexor fibularis*, while, to its real homologue, the names *tibialis posticus accessorius*, *secundus*, or *internus* had been given.

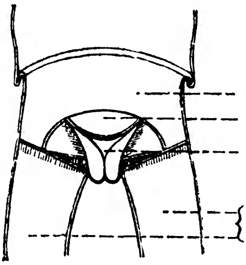
The author showed that the tendon of the *flexor tibialis* which, in most species of placental mammals unites in the foot with that of the *flexor fibularis*, in many species (belonging to certain families) of insectivora, edentata, and rodentia, and apparently also in all implacental mammals, becomes separated from its connection with that muscle, and attaches itself instead to some part of the tibial margin of the foot, or to the plantar fascia and integument of the sole. An analysis of these two leading conditions of the muscle is shown in the table below, and gives interesting results, the significance of which was fully discussed.

Flexor digitorum tibialis, united in the foot with the Flexor digitorum fibularis		Flexor digitorum tibialis, not connected in the foot with the Flexor digitorum fibularis		
I. Insectivora	Chrysochloridæ Centetidæ Solenodontidæ Potamogalidæ Tupaiidæ Galeopithecidæ	I. Insectivora	Talpidæ Soricidæ Erinaceidæ	I. Monotremata.
II. Chiroptera.				II. Marsupialia.
III. Rodentia	Hystricomorpha Lagomorpha	III. Rodentia	Sciuromorpha Myomorpha	
IV. Edentata	Orycteropodidæ	IV. Edentata	Dasypodidæ Bradypodidæ Manidæ	
V. Hyracoidea VI. Ungulata VII. Proboscidea	*No tibialis posticus*			
VIII. Carnivora.				
IX. Primates.				

[1] Subsequently published *in extenso* in the *Journ. of Anatomy and Physiology*, vol. xvii. (1882–3).

4. *On the Nature of the 'Telson' and 'Caudal Furca' of the* Crustacea. *By* Dr. M. M. Hartog.

The author gave a short account of the different views held on the nature of these parts. His own explanation of them is as follows: In *Copepoda* the anus is a terminal-dorsal slit; the tergum of the last segment (which is prolonged into the furcal process on either side the anus) is produced into a semicircular plate, overhanging the anus, which may hence be termed the 'supra-anal plate.'



If this plate is produced further and becomes more or less adnate to the furcal processes, the anus is pushed down thereby, becoming, first, terminal-ventral (*e.g.* phyllosoma larva of *Palinurus*), and then truly ventral. In the *Astacus*, &c., the furcal processes are visible as lateral truncate setose knobs projecting at the sides of the telson a little posterior to the anus.

Embryology also confirms the view taken that the telson of the higher *Crustacea* is equivalent to the *last segment of the nauplius body, together with an immensely developed post-anal portion composed in varying proportions of the supra-anal plate, and the adnate furcal processes.*

The furcal processes are regarded as outgrowths of this somite, not strictly comparable to limbs, but rather to *those primitive paired outgrowths of the body-segments which have become limbs elsewhere by the development of basal articulations and a proper musculature,* specialisations which are unneeded in this segment attached only at its anterior end.

SATURDAY, AUGUST 26.

The Department did not meet.

MONDAY, AUGUST 28.

The following Papers were read:—

1. *On the Perception of Colour in Man and the Lower Animals. By* J. D. Macdonald, *M.D., F.R.S.*

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2. *An improved Method of directly determining the Velocity of the Contraction-Wave in Curarised Muscle. By* Professor E. A. Schäfer, *F.R.S.*

The method here briefly described is a modification of the one which was originally employed by Aeby. This, which was not only the first, but still remains the only direct mode of determining the velocity of the contraction-wave, consists in resting upon the muscle at a carefully measured distance from one another, two

light levers which are made to write upon the same moving surface; the muscle is then stimulated at one end; the wave of contraction, in passing along the fibres, raises the levers in succession, and the space intervening between the commencement of the curve described by the one lever and that of the other, gives the time taken by the contraction-wave to traverse the portion of muscle between the levers. From these data the velocity of the wave is readily calculated.

It is found, however, that the measurements obtained by this method are of much less value than those deducible from measurements of the rate of conduction of an excitation along the muscular fibres, or of the rate of passage of the electric changes which result from stimulation; indeed, it is scarcely possible to obtain any exactitude by its means, on account of the difficulty in determining exactly the points at which the muscle-curves described by the levers begin.

In order to obviate this difficulty I have caused the levers, instead of writing directly upon a moving surface, successively to break galvanic circuits connected with a Ruhmkorff induction-apparatus, the ends of the secondary coil being so arranged that the sparks are transmitted through a sheet of smoked paper, moved rapidly by means of a strong spring-myograph; a time-tracing is at the same time recorded on the paper by a chronograph. The interval between the pricks in the smoked paper caused by the sparks, gives with great exactness the time occupied by the contraction-wave in traversing the distance between the levers.

The (vulcanite) levers employed for the purpose are about six inches long and of the third kind. They are so hinged at the fulcrum as to permit no lateral play, and at a distance of about two inches from the fulcrum a thin piece of steel is rigidly fixed so as to depend vertically; the lower end of this rests on the muscle.

Each lever carries at its free end a small semicircular bridge of copper wire, the ends of which are bent downwards; one end terminates in a platinum point, and the other end is amalgamated. Immediately beneath the platinum point is a plate of the same metal, capable of being raised up by means of a screw, so as to be brought in contact with the point; and beneath the amalgamated point is a small cup containing mercury, the surface of which can also be raised by a screw (as in the Helmholtz 'double-contact' arrangement employed in the 'Frosch-unterbrecher' of du Bois-Reymond), so as to touch the amalgamated point, and by subsequently depressing the mercurial surface, remain connected with it by a thread of mercury only. By this contrivance any current which may be passing through the wire from the platinum plate to the mercurial cup, or *vice versâ*, is broken at the point of contact with the plate the instant the lever is raised, but in consequence of the breaking of the mercurial thread, the circuit is not closed again when the lever falls, until the mercurial surface is again raised by the screw.

In experimenting with this apparatus especial attention must be directed to the regulation of the contact between the platinum point and plate, the latter being screwed up with the greatest possible care, so as only just to make contact with the point.

The results which I have obtained by this method, although not yet sufficiently numerous for detailed publication, have given a considerably higher velocity (between 2 and 3 m. per sec.) than those yielded by the original method of Aeby.

A modification of the above method consists in the adoption of Pouillet's method of time-measurement. The arrangements for this purpose are simpler, the spring-myograph and the Ruhmkorff being dispensed with and their place taken by a galvanometer. The second copper bridge, *i.e.* the one attached to the further lever, is introduced directly into the galvanometer-battery circuit (by connecting the wires of this circuit with its platinum plate and mercurial cup), but the first copper bridge is so connected laterally as to short-circuit the current. The raising of the first bridge, therefore, sends the current through the galvanometer, and the raising of the second bridge breaks the circuit. During the interval between the raising of the levers the current has been acting upon the galvanometer, and the length of time it has been passing can be ascertained by noting the extent of deflection of the galvanometer-needle.

3. *Note on the Structure of the Muscular Tissue of the Leech.* *By* T. W. SHORE, Jun., *B.Sc.*

After detailing his observations on the fresh muscle-tissue of the leech, and describing the action of reagents, the author sums up as follows:—

1. The muscle-tissue of the leech consists of elongated tubes with two coats—the sarcolemma and contractile layer—the inner surface of which is irregular, and gives rise to apparently granular contents.

2. In the living condition it is unstriped.

3. There are no nuclei, and the contents are a colourless serous fluid.

4. Transverse striation may be produced *post mortem* as the result of three sets of changes:—

(*a*) Regular arrangement of the papillæ on the inner surface of the contractile layer.

(*b*) Foldings of the surface of the sarcolemma.

(*c*) Splitting into segments of the contractile substance.

5. The contractile substance coagulates, forming myosin, which subsequently contracts.

6. The rapidity of and mode of contraction give rise to varying appearances of fissures, striation, &c.

He then passes on to a discussion of the bearing of these results on other considerations, and finally suggests a new theory as to the structure of striated muscle-tissue.

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4. *On the Kidneys of Teleostei.* *By* W. NEWTON PARKER.

In a paper read last year at the British Association, the late much-lamented Professor Balfour showed that in certain adult Teleostei, as well as in Lepidosteus and Acipenser amongst the Ganoids, the so-called 'head-kidney,' or pronephros, contained no uriniferous tubules, but was composed entirely of highly vascular lymphatic tissue. He therefore considered it probable that there were no functionally active remains of the pronephros in the adults of either of these groups.

The author of the present paper, in following up these investigations, finds that in some Teleostei the so-called 'head-kidney' has precisely the same structure as the rest of the kidney, or mesonephros. He nevertheless holds to Balfour's view as to there being no functionally active remains of the pronephros in the adult, and explains the above cases by supposing that the mesonephros has grown forwards in front of the air-bladder, where there is most room for it, so as to take the place of the larval pronephros. That this is not improbable is shown by the great variation in the form and position of the mesonephros in different species of fishes.

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5. *On the presence of a 'Tympanum' in the genus Raia.* *By* GEORGE BOND HOWES.

The author regards a fenestra (long known to exist) in the roof of the auditory capsule of the genus, and its adjacent parts, to be a modification of what is seen in other species, which is correlative of the compression from above downwards undergone by it, resulting in the formation of a '*tympanum*' physiologically foreshadowing the essential process involved in the elaboration of the auditory organ of the higher forms, the real bearing of which has hitherto escaped notice.

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6. *On some Toxic Conditions of the Blood, illustrated by the action of Hydrocyanic Acid.* *By* THOMAS S. RALPH, *M.R.C.S.*

The author satisfied himself of the occurrence of amyloid bodies in the blood, a blue reaction being produced by the administration of hydrocyanic acid, and

suggested the possibility that there may be a quasi-spontaneous formation of some 'cyanoid' poison in the blood.

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7. *Upon some new Methods of investigating the Physiology of the Mammalian Heart. By* Professor H. N. Martin.

TUESDAY, AUGUST 29.

The following Papers were read:—

1. *Considerations arising from Koch's Discovery of the Bacillus of Tuberculosis. By* F. J. Faraday, *F.L.S.*

Two great discoveries, Pasteur's discovery of the decreasing virulence of specific disease-germs when kept in the presence of oxygen, and Koch's discovery of the bacillus of tuberculosis, have been made within the past two years. The author suggests a possibly useful relation between these discoveries. Referring to the suggestion of Dr. William Roberts, F.R.S., of Manchester, in his address to the Medical Association in 1877, that disease germs may be 'sports' from harmless saprophytes which have acquired a parasitic habit, he asks whether deprivation of oxygen, or cultivation in gaseous mixtures from which the normal supply of free oxygen present in good air is absent, may not have an influence in converting harmless germs present in the atmosphere into the bacilli of tuberculosis. He refers to Carl Semper's researches on the influence of the environment on animal modification, and to the fact that many larvæ of insects live in situations where the air is undoubtedly mixed with gases which the higher vertebrata could not breathe without injury, and suggests that the adaptability of organisms, and their impressionability by surrounding conditions, may increase as the scale of life is descended. He also refers to a paper by Mr. Frank Hatton, F.C.S., read before the Chemical Society, on experiments with bacteria in various gases. Mr. Hatton gave the chemical results, but it would be interesting to know the influence of cultivation in such media on the character of the bacteria themselves. Dr. Angus Smith has argued that the putrefying process, when carried on in confined places, such as sewers, may develope disease-germs which are not developed when the same process goes on in unconfined places; typhoid fever seems to be developed by processes in sewers which, carried on in the Clyde for instance, do not originate any well-marked disease. Analogous conditions may be presented in the lungs of persons engaged in dusty trades, breathing vitiated atmosphere in ill-ventilated rooms, or engaged in sedentary occupations, and not taking healthy exercise; and also in the lungs of persons who are hereditarily narrow-chested, weakly, and of feeble inspiratory habit. Innoxious germs present in the atmosphere may be inhaled and retained in the lungs of such persons, and there by successive culture and deficient aëration acquire a parasitic or deadly character. The author refers to Pasteur's method of restoring the virulence of 'attenuated' germs by successive culture in the bodies of different animals, as possibly explaining the communication of tuberculosis to persons of sound constitution, the parasitic habit of the tubercle 'sport' being so strengthened and confirmed by successive culture under the assumed favourable conditions, as to enable it eventually to establish itself under certain conditions in a *milieu* which would not be suitable for the origination of the culture. He refers to a new treatise by Dr. Ferdinand Kroczak, of Brünn, entitled 'Die Heilung der Tuberculose,' and shows that Dr. Kroczak's arguments in support of the special treatment recommended by him are in harmony with the hypothesis advanced.

The decrease of mortality from consumption in the army since the improvement of barrack ventilation, and the relief afforded to patients by sea voyages, the air of

pine-woods, carbolic-acid inhalations, and by other suggested remedies, is also referred to as giving support to the hypothesis.

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2. *Remarks on Filaria Sanguinis Hominis. By* Dr. COBBOLD, *F.R.S.*

The author gave a full account of the relations subsisting between the larval microscopic filariæ occurring in man, the higher larval stages of the same parasite occurring within the body of the mosquito, and the sexually mature form, or *Filaria Bancrofti.* The development of the parasite, as made known by the researches of Manson, were carefully described, and the phenomena of filarial periodicity were explained by means of a series of large diagrams. The author maintained, contrary to the views generally held, that the bloodsucking propensities of the mosquito had more to do with the heating of the ova of the insect itself than with any immediate purpose of self-nourishment. The provision for the welfare of the filariæ and their reproduction was thus, in a truly remarkable manner, intimately bound up with the welfare of the insect. In the course of the paper the author specially referred, not only to the brilliant results obtained by Manson, but also to the discoveries of Drs. Lewis, Myers, and Stephen Mackenzie.

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3. *On the Destiny of the Filaria in the Blood. By* Dr. P. MANSON.

In this paper (communicated by Dr. Cobbold), the author dealt with the question of the fate of the embryo parasites which have not been directly removed from the circulation by mosquitoes. He asks:—'Do they, after a brief life of a few hours, die?' And again: 'Do they daily retire to some organ, or set of vessels, to await the recurrence of conditions that induce them to return to the circulation? Dr. Manson had kept the larvæ alive in the serum of blood for more than 100 hours. Dr. Myers has expressed an opinion that there is a daily dissolution of the filariæ, but Dr. Manson combats this view, and from his observations is led to conclude that it is unreasonable to suppose that 'animalcules exhibiting such tenacity of life outside the body should so quickly die within it.' As bearing upon this subject he also remarks: 'I do not recollect ever to have seen in freshly drawn blood a dead filaria, at least one parasite whose death could not be easily accounted for by accidental crushing under the glass cover.' [1]

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4. *Note on the Early Development of Lacerta Muralis. By* W. R. WELDON, *B.A.*

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[1] A fuller report of the author's latest researches appeared in the *Customs Gazette* for 1882.

DEPARTMENT OF ZOOLOGY AND BOTANY.

Chairman of the Department—Professor M. A. Lawson, M.A., F.L.S.
(Vice-President of the Section).

THURSDAY, AUGUST 24.

The Department did not meet.

FRIDAY, AUGUST 25.

The Chairman delivered the following Address:—

Although the President of this Section has made eloquent allusion to the great loss which the whole scientific world has sustained in the death of our great countryman, Charles Darwin, still I am sure I shall not be thought to be doing more than is my bounden duty if I, too, from this chair give some utterance to the deep sense of irretrievable loss which all we in this department must feel has fallen upon us.

It is not my intention to give an account of Mr. Darwin's numerous works, for that has already been partially done by abler hands than mine, and a complete survey of his labours would occupy much more time than that which is usually allotted to an address such as this. At the same time I think that in this department we are particularly called upon to give utterance to some expression of our feelings, inasmuch as we may be said to have been more concerned in those matters of which Mr. Darwin was teacher than any other section of the Association. It was upon this platform, more than in any other place, that the great battle of the doctrine of evolution, which is so intimately connected with Mr. Darwin's name, was fought. It was upon this platform that his friends and coadjutors—Mr. Alfred Wallace, Sir Joseph Hooker, Professor Huxley, and many others—expounded his views, and added by their own researches to the sum of evidence which has finally convinced all the leading scientists of the day of the substantial soundness of his speculations.

There are many of us now present who will never forget the intense interest and excitement which attended the discussions which took place in the earlier days of the history of the doctrine of evolution; nor shall we forget with what bitterness Mr. Darwin's views were met, on the occasion of the Association's meetings at Oxford, Cambridge, Norwich, and Exeter; nor how everything that came from his pen was regarded with feelings of suspicion and hatred; and how even his blameless and guileless character was frequently assailed by those who could only see in his works a desire to dethrone all that which they considered sacred. It is also in the recollection of all of us here how he met the attacks which were made upon him with silence, never returning opprobrious declamation or insulting sarcasm by angry or contemptuous answers. Ever conscious that his aim was to search out the truth and that only, he could afford to disregard contumely and misrepresentation. Indeed, so completely was he imbued by the consciousness that his aim was righteous, that the taunts and sneers which were lavished upon him seem to have been powerless even to vex him. Again, we in this department will remember how these attacks year by year grew less frequent and less bitter; how wholesale denunciation gave place to legitimate questionings of particular points, and how even personalities at last gave place to general professions of esteem and respect; till at last, but a few short months ago, we witnessed the burial of his remains in

the national mausoleum, and saw his coffin followed not only by scientists and laymen, but by priests of various religious denominations, all of whom sought by their presence to testify to their recognition of his great worth; and perhaps some to atone in a measure for the unjust things which they might have said or thought about him, when they were unacquainted with his character, and only half-acquainted with the object and nature of his labours.

But although our hearts are still sore at the remembrance of our loss, there are many things the reflecting upon which may well console and reconcile us to it.

In the first place he had been spared to us till such a time as we were able to walk without further needing the assistance of his guiding hand; and the work which had occupied him all his life had been so far finished that it can now without difficulty be carried on by his disciples.

In the next place, his life, although far from having been free from suffering, had been prolonged to a green old age, and he was able and delighting to work almost to the very day of his death. He had the satisfaction of looking back upon a long life happily and worthily spent. He had the satisfaction of living to see the doctrines which he had promulgated gradually acknowledged, and finally universally accepted. He was surrounded by devoted friends, and regarded by all naturalists with a reverence and affection such as has fallen to the lot of none since the time of Linnæus.

If, however, we have consolation in the remembrance that the lamp of Charles Darwin, which had burned so brightly, had also burned its full time, we have none such in the case of that other bright light, which has lately been so unexpectedly extinguished. In the lamentable death of Francis Balfour, at the early age of thirty, we can only feel unmixed regret.

He had already done great things, and we had a right to hope that he would have lived to achieve greater things still.

He had just been appointed to a professorship in Cambridge, where everyone confidently looked forward to his doing in that University for morphology what his master and friend had done before him in physiology; to his inspiring his pupils with a true love of his branch of science, and making them, like himself, original observers and workers. Everyone, too, made no doubt but that he would further follow out those elaborate researches in the development of the early stages of growth in animals, which had already made his name known and honoured wherever in the world the subject of animal morphology is studied.

But all these hopes have been cruelly destroyed by that fatal accident which occurred to him while travelling in search of recreation and health on the Alps of Savoy. Without impiously wishing too closely to scrutinise the decrees of heaven, we cannot help asking why he, who could be so badly spared, should have been taken, while the thousands, who would not have been so much missed, and who every year risk something in climbing the Alps, should yet escape without injury.

It is now eight years since Mr. Bentham communicated to this department, at Belfast, his report 'On the Recent Progress and Present State of Systematic Botany,' and I propose to take for the subject of my address to-day the advances which have been made in this branch of botany since that date.

Mr. Bentham, for the more easy consideration of the subject, classified the various works relating to systematic botany under six heads. And I do not think I can adopt a more convenient plan than to follow upon the same lines.

The six heads were as follows:—

1. *Ordines Plantarum.* Being general treatises on descriptive reviews of the natural orders.
2. *Genera Plantarum.* Being the methodical enumeration and descriptions of genera.
3. *Species Plantarum.* Being the methodical enumeration and descriptions of species.
4. Monographs of separate orders or genera, sub-genera, or species.
5. Floras of separate countries or districts.
6. Detached and miscellaneous specific descriptions.

1. *Ordines Plantarum.*

Under this head I have no work of importance to bring before your notice.

Indeed it is not to be expected that works of this kind should appear at more than very rare intervals; for not only do general treatises on the relationships of natural orders require for their successful treatment an intimate acquaintance with vegetable morphology, both gross and minute, but there must also be a special acquaintance with the life-history of a large number of individual species belonging to each order. And, moreover, this very extended knowledge (which is possessed by few botanists) must be accompanied by an acutely logical mind and great soundness of judgment.

2. *Genera Plantarum.*

For the same reason that works descriptive of the orders of plants appear but rarely, so are works descriptive of the genera of plants few and far between. Indeed, where there is an attempt to describe all the genera belonging to the Phanerogamia, such works are less frequent; inasmuch as the mechanical labour of dissecting the innumerable number of species of which the genera are composed, and of writing out a description of them, is infinitely greater.

I have, however, the great satisfaction of being able to record the near completion of that monument of original research and industry, 'The Genera Plantarum,' by Mr. Bentham and Sir Joseph Hooker. This work, the publication of which has extended over a period of exactly twenty years, consists of three large octavo volumes, each of which contains over one thousand pages of closely printed matter. In these pages are described the genera belonging to the angiosperms and gymnosperms, amounting in all to the enormous number of something like 7,400. Simply to compile from works so large a number of genera would entail an immense amount of labour. But when we know that each genus has been critically investigated by one or other of the authors, not only as regards the characters, which were to determine its limits and explain its affinities with other genera, but also as regards its synonymy, which, in many instances, had become fearfully involved; and when we add to this the knowledge that the geographical distribution of each genus has been carefully worked out, we can only marvel that so much should have been done so quickly.

No doubt, as time goes on, and new plants are discovered, and more complete information is gained respecting old ones, it will be found necessary to revise the characters and limits of some of the genera. And when all is done, there will be differences of opinion in many cases as to where the limits may be most conveniently placed. Nevertheless, there can be little room for not believing that, in by far the greater number of instances, the genera as here defined will be accepted as fixed so long as our present nomenclature exists.

3. *Species Plantarum.*

Under this head again, so far as the Phanerogamia are concerned, there is nothing new to report. Nor do I think there is any likelihood that any general work, including all the species which are known, will be forthcoming for many years. Indeed, I do not feel sure that it would be desirable at present that any one should attempt such a work. And for the following reason.

Within the last few years, many parts of the world, which were formerly unknown or closed to us, are beginning to be thrown open to our collectors; and we have had already a large number of new species sent home. But in many of these parts, our collectors have really been able to do little more than snatch at the flora, as they have hurried through on some rapid journey. Hence we may fairly expect that for many years to come there will be more new species constantly turning up. This being so, I think it might be better that we should wait a little longer till the list of known plants approaches nearer completion.

Meanwhile, there is a great deal of needful preparatory work, which is being done; such as the carefully comparing every new species with those already known,

and more particularly still, the unravelling that dreadful synonymy which clogs and fetters the systematist at every step.

Amongst the cryptogamia, I have to make mention of the completion of Jæger's 'Adumbratio Floræ Muscorum.' This work was begun in the year 1871 and carried on by Dr. Jæger until his death, when after a short interval it was recommenced and finally finished by Dr. Sauerbeck two years ago. With its two supplements, the 'Adumbratio' enumerates 335 genera and 7,422 species, and gives, so far as it is known, the geographical range of each species over the world. There are, however, no descriptions of the species, but the muscologist is referred to the various publications in which these—at least the more recently described ones—have originally appeared. The synonymy, which in mosses is as extensive and as confused as in any other group of plants (always excepting the ferns), is in many cases imperfectly worked out; and the difficulty of finding a species or its synonym is further enhanced by there being no index. But notwithstanding these defects, the last of which might easily be remedied, the work is one of considerable value to those who have to arrange in an herbarium large collections of mosses, and it will save anyone, who may hereafter undertake the task of writing a 'Species Muscorum,' a vast amount of preliminary labour. Whether the numberof genera and species —and especially the genera—have been unduly increased by overdividing is a subject on which there will be considerable difference of opinion; but as a matter of convenience the system of having big genera, with sections, is much to be preferred to that of having a number of small ones; if only on account of the great multiplication of names which the latter entails. In the case of species, the kind of names, which have been given of late, are suggestive of sub-division having been carried too far. For instance. we have many so-called species the names of which are made up of some old well-known species and the prefix '*pseudo*' or '*sub.*' Thus in the genus Hypnum we have no less than twenty-seven names beginning with '*pseudo*,' as *Hypnum pseudo-commutatum*, *Hypnum pseudo-populeum*, or *Hypnum pseudo-velutinum*; while in the same genus under '*sub*,' such for instance as *Hypnum sub-imponens* or *Hypnum sub-rutabulum*, we have no less than forty-nine such names.

4. *Monographs of separate orders, or genera, sub-genera, or species.*

There are several important monographs, which have been written during the last few years; and perhaps none more so than those which have made their appearance under the auspices of the two De Candolles (father and son), in continuation or revision of the 'Prodromus.' In the three volumes as yet published there are ten orders, which have been monographed. The orders are—

Smilaceæ	by Alphonse De Candolle.
Restiaceæ	by Dr. Masters.
Meliaceæ	by Casimir De Candolle.
Araceæ	by Engler.
Phylydraceæ	by Caruel.
Alismaceæ, Butomeæ, Juncagineæ	by Michel.
Commelinaceæ	by C. B. Clarke.
Cucurbitaceæ	by Cogniaux.

It will be noticed that of these ten orders eight belong to the monocotyledons. This will be welcomed by all botanists, as it is this portion of the phanerogamia which has been most neglected.

Another of the monocotyledonous orders, which has been worked out at great length by Von Otto Boeckler in 'Linnæa,' is Cyperaceæ. But as his writings extend over no less than seven volumes of that journal, it is an awkward work to use, let alone that his arrangement and limitation of the species is not always easy to understand.

In Gramineæ, botany has received a great blow in the unfortunate death of General Munro, who, had life been spared to him for a few years longer, would doubt-

less have given to the world one of the most satisfactory accounts of that large and difficult order which has ever appeared. But now, unfortunately, all idea of speedily seeing a monograph of the species of Gramineæ must be given up, although, as far as the genera go, we shall soon have Munro's labours presented to us by Mr. Bentham, together with his own, in the forthcoming part of the 'Genera Plantarum.'

Mr. Baker still continues his researches on the Liliaceæ and Iridaceæ, publishing from time to time monographs of the species of varicus genera belonging to those orders. Both of these orders present many difficulties in the way of those who attempt to arrange and describe the species, partly on account of the general succulency of the plants, and partly because many of the more important characters are to be found only in those portions of the plant which frequently grow under ground; such as the corn of crocus, or the rhizome of iris, and which are often absent from herbarium specimens. And, again, owing to the beauty of their flowers, they have always been great favourites with horticulturists, who have split up the species and multiplied the names to an inordinate extent.

The largest order among the monocotyledons (the grasses not excepted, according to Mr. Bentham) is orchidaceæ, the species of which are still being carefully described and figured chiefly by Professor Reichenbach; but in so many different places that, to a great extent, his most valuable labours are not rendered as available as they ought to be. A single work combining all Professor Reichenbach's own researches with those of others, and forming a sort of second 'Genera et Species Orchidearum,' would leave nothing further for the botanist to desire.

One other monograph which I must mention is that of 'Cyrtandreæ,' by Mr. C. B. Clarke. This, which is nearly ready for the press, will include a description of the characters and geographical distribution of all the species of that most difficult and hitherto but little known order.

5. *Floras of separate countries or districts.*

It is under this head that we have had the greatest amount of activity shown.

The conditions, which at present obtain, are particularly favourable for the compilation of floras, when compared with what they were twenty or thirty years ago. In those days working botanists were few; now there are many enthusiastic and excellent ones resident in all parts of the world, and who are not only able but willing and eager to assist in any undertaking which may tend to perfect our knowledge of the plants of their particular country. Consequently, not only is the material which is sent home much greater than it used to be, but it is accompanied by valuable information, such as could be given only by experts living in the districts where the plants grew.

I proceed now to enumerate the more important floras which have either made their appearance or have been completed within the last eight years.

1. First and foremost I have to make mention of those floras, which are being published under the authority of our colonial Governments; and among these there stands out most prominently of all 'The Flora Australiensis' by Mr. Bentham, assisted by Baron Ferdinand von Mueller of Melbourne. This work, the first volume of which was issued in the year 1863, was completed with the publication of the seventh and last volume in 1878. These seven volumes describe all the species of Phanerogams and Vascular Cryptogams, which are known to grow in Australia and Tasmania. The description of the species is sufficiently detailed without being cumbersomely long, and the affinities of any, when doubtful, are always commented upon; and useful suggestions made for their more accurate determination, by those who may hereafter have better opportunity for their study.

The information respecting the distribution of each species is also very full. For the sake of convenience the country has been divided into areas, corresponding to the territories of the different colonies, viz. Queensland, New South Wales, Victoria, Tasmania, South Australia, and West Australia; and as a species is known to grow in one or more of these areas so it is indicated; and not only this, but mention is also made of the particular place or places in the colony in which it has been found. So that while we have a flora which describes all the plants of

this immense island, the colonists have, for all practical purposes, no less than six local floras. Again, in addition to this, when the species is not confined to Australia, its distribution over other parts of the world is given.

2. Next in importance to the 'Flora Australiensis,' and what when finished will be of even greater magnitude, comes the 'Flora of British India' by Sir Joseph Hooker. This work was begun in the year 1872, and was continued with the assistance of various botanists to the end of Myrtaceæ. Since then—and the world will have no reason to complain of the change—it has been carried on by Sir Joseph Hooker and Mr. C. B. Clarke alone. It has now reached to the commencement of Vaccinieæ, and more parts may be shortly expected, which will carry the work forward to the end of Monopetalæ.

The 'Flora of British India' takes in the whole of that country which lies between the southern slopes of the Himalayas and Ceylon. Besides this it includes the British portion of the Malayan peninsula, and the islands which lie between that country and India proper. Thus it will form the connecting link between Western Asia on the one hand, which is being described by M. Boisseau in his 'Flora Orientalis,' and on the other with the floras of Sumatra and Java, which have been so carefully elaborated by Blume, Miquel, and others.

Many portions of the vast tract covered by these and other authors, such as Borneo and New Guinea, can hardly yet be said to have been properly explored, and therefore, many new genera and species may be yet expected to occur; still it is not likely that the additions will comprise more than a small proportion of what is already known.

It is computed that when the 'Flora of British India' is completed, it will contain descriptions of some twelve to fourteen thousand species of phanerogams and ferns.

In some respects the difficulties attending the elaboration of the Indian flora are greater than in the case of any other country. In the first place, the climate of a large portion of the land is so humid, that the satisfactory preservation of specimens by drying is almost impossible. The consequence of this has been that a great deal of the material, placed at the disposal of authors, has often been very defective. In the second place, the literary difficulties are unusually great; for India, through having been so long known to Europeans, has been more or less explored by botanists, who for the last hundred and fifty years have been writing with very commendable diligence, but varying ability, descriptions of all the plants they met with. These writings are very numerous, and by themselves form a library of no small dimensions. But all have to be searched out, and their contents, often very misleading, carefully digested.

3. In Mr. J. G. Baker's 'Flora of the Mauritius and the Seychelles' we have another of the colonial floras of much worth and exactness; and one which, with Professor B. Balfour's researches into the vegetation of the island of Socotra, helps to bridge over the gap between the South Asiatic and Eastern African floras. From Mr. Baker's pen we may hope to have also before long a Flora of Madagascar.

4. The 'Flora of Tropical Africa,' by Professor Oliver, was begun in the year 1868, and continued, with the assistance of other botanists, to the end of the third volume, which was published in 1877, by which the work has been brought down to the end of 'Ebenaceæ.' Since then for various causes it has been at a standstill. But we may be permitted to hope that ere long it will again be resumed; for the collection into one book of all the species which are known to grow within the tropics of Africa would be extremely convenient, as the number of writers on African botany, if not as great as those on India, is still sufficiently great to make the identification of specimens a matter of very considerable labour. No doubt, when finished, the 'Flora of Tropical Africa' will not approach to anything like the completeness of the other floras which I have mentioned, for of all parts of the world Central Africa has up to the last few years been hidden in obscurity, and the number of species, which were known when the first volume was issued, probably did not exceed the number of those which had still to be discovered.

5. I may mention the 'Flora Capensis,' by the late Dr. Harvey and Dr. Sonder (although it neither was begun nor has been continued during the last eight years), if only to point out that if completed the flora of the whole of Africa south of the

tropics would then have been described. At present it has been carried as far as Campanulaceæ.

Turning from our colonial floras, we have a work of very great importance, to which I have already made allusion; I mean the 'Flora Orientalis,' by M. Edmond Boissier. Since 1874 two more volumes (viz. the third and fourth) have made their appearance, bringing the description of the species down to the end of 'Apetalæ.' This work, roughly speaking, includes all that tract of land which lies between the northern tropic and the forty-fifth parallel, and between the twentieth and seventieth degrees of longitude. It takes in the following countries:—Greece, Turkey, Upper Egypt, Northern Arabia, Syria, Asia Minor, Caucasia, Persia, Afghanistan, Beloochistan, and the greater portion of Turkestan; and, as I have pointed out before, its boundaries on the east are in the greater portion of their extent identical with the western boundaries of the Flora of British India.

6. Coming to Europe we have had a most valuable contribution towards the future writing of a flora of the whole continent in C. F. Nyman's 'Conspectus Floræ Europææ,' the third part of which was published last year, and completed the Dicotyledons and Gymnosperms. Although the Conspectus gives no descriptions, the chaotic mass of synonyms, with which many of our European floras abound, has been carefully investigated; and the distribution of each species over the continent has been minutely recorded. So that the conversion of the conspectus into a flora would not entail any very large amount of labour. Indeed, may we not hope that seeing with what universal approbation the conspectus has met with, Dr. Nyman may be induced to enter upon the conversion himself? Such a flora has never existed. The nearest approach to such a one was Mr. Wood's 'Tourist's Flora.' But this took in a portion only of Europe, and was in many other respects an unsatisfactory production.

7. Among the smaller territorial floras which have appeared, I may mention the 'Compendio della Flora Italiana,' by Giovanni Arcangeli, which gives a complete account of the Phanerogams and Vascular Cryptogams of the Italian Peninsula.

8. In North America we have several works of note to remark upon. First, we have had a volume containing the botany of that portion of California which is now included among the United States; the Polypetalæ of which are from the pens of W. H. Brewer and Sereno Watson, and the Gamopetalæ from that of Professor Asa Gray.

From Professor Asa Gray we have also the first part of the second volume of a work entitled, 'Synoptical Flora of North America.' It is intended that this shall take the place of the 'Flora of North America,' by Torrey and Gray, but which was stopped thirty-five years ago at the end of the order of Compositæ. The present work begins where the old flora left off, and concludes the description of all the Gamopetalæ after Compositæ. The remaining parts of Vol. II. will include the Apetalæ, Gymnospermæ, Monocotyledons and Vascular Cryptogamia. It is then intended to rewrite the old flora, adding the new material, which has come in since its date, and to issue the new production as Vol. I. of the 'Synoptical Flora.'

These two volumes will describe the plants which grow in that part of North America which includes Canada and the United States, together with their adjoining islands, Greenland excepted. The number of species to be described from this vast and varied tract of country will probably not fall far short of 12,000.

9. Joining on to this we have the 'Botany of the Biologia Centralis Americani,' by Mr. W. B. Hemsley. Two large volumes are already published, while the third and last one is rapidly progressing. Mr. Hemsley's Flora will include some 15,000 species, which grow south of the United States, and north of Panama. These two floras with that of Professor Grisebach's 'Flora of the West Indian Islands,' will include all that is known of North and Central America with their adjacent islands.

10. In South America, Martius' magnificent 'Flora of Brazil' has been advanced by various authors, who have monographed orders or portions of orders. The length of time over which this vast work has been spread will render a new edition necessary, on account of the earlier volumes having become antiquated. When any such edition is brought out, it is to be hoped that it may partake more of the

nature of one of our colonial floras than of its present form, for the cost of the present superb work is such as to place it beyond the means of any but the most wealthy. The plates too, which add so largely to the cost of the present work, would not be needed.

11. Leaving the 'Flora of Brazil' by von Martius, and turning to the western side of the South American continent, we have from the pen of Fr. Philippi an extremely valuable catalogue of all the plants which are known to grow in Chili, together with a revision of their synonyms and a statement concerning the geographical range of each species. This catalogue, like Nyman's 'Conspectus Floræ Europææ,' will render the writing of a future flora of Chili a comparatively easy task. Such a flora is greatly needed, for not only is Gay's out of print and very scarce, but it has also become antiquated.

These, I think, are the chief floras, or special aids to new floras, which have appeared during the last eight years, and I pass on now to the sixth and last head.

6. *Detached and miscellaneous specific descriptions.*

It would be impossible for me to enumerate even the titles of all the papers that have been written on systematic botany in the different transactions and journals of the various learned societies, and I shall therefore content myself with mentioning some few of those which I consider most interesting.

First: In the 'Transactions of the Linnæan Society,' Mr. Bentham, in his revision of the sub-order Mimoseæ, has given us another of those beautifully complete reviews of a most difficult group of plants, for which he is so celebrated. Like all his works of this kind, he presents us not only with descriptions of all the genera and species, but he also contrasts the characters on which the former are founded, in such a way as to leave those who study his works perfectly clear as to the principles by which he has been guided in arriving at a determination as to what shall be sufficient or insufficient for the formation of his genera and sub-genera. Under each species he has also given us a complete account of its geographical distribution; and he has added extensive lists of all the numbers, which have been distributed with the dried specimens of the better known collectors. This last addition is, for those who have the arrangement of herbaria to superintend, of very great value, for it not unfrequently happens that a specimen which may exhibit many useful and important points, may also just be wanting in some particular character, without which its right genus or species cannot be determined. The quotation of the number overcomes the difficulty, and thus makes the partially imperfect specimen of very considerable service. In another volume of the same Transactions, Professor Oliver and Colonel Grant have given us an account of all the species which formed the collection made by the latter gentleman, on his celebrated expedition with Captain Speke, through that portion of Central Africa which lies between Gondokoro, Victoria N'yanza, and Zanzibar. This account is accompanied by 136 plates, containing the portraits of about 140 new or interesting species which had not been previously figured. This is without doubt the most extensive addition to our knowledge of the flora of Tropical Africa which has been made for many years, and which, with Professor Schweinfurth's labours, has done more than any other work to give us an insight into the vegetable riches which are yet in store for us in Central Africa.

I may mention also the following papers of considerable interest which have been printed in the Linnæan Society's Transactions:—1. A report, by Mr. J. G. Baker, on some new monocotyledonous plants, from Welwitsch's 'Angolan Herbarium.' 2. A review of the ferns of Northern India, by Mr. C. B. Clarke.

Turning from the 'Transactions' to the 'Journal of the Linnæan Society, we have several excellent papers, by Mr. Baker, on many of the genera belonging to the natural order Liliaceæ. We have also from the same botanist an enumeration of all the known species of Iridaceæ, together with descriptions of such as have not hitherto been described. In the sixteenth volume of the same journal we have a long and most useful paper by Mr. Ball, entitled *Spicilegium Floræ Maroccanæ*, in which all the plants known to grow in the territory of Morocco have been carefully

catalogued. Amongst these are many species formerly unknown to science, of which descriptions, and in many cases plates, have been given. The Spicilegium, as most botanists here know, was the result of an adventurous raid made by Mr. Ball into the region of the Atlas country, in company with Sir Joseph Hooker and Mr. George Maw, in the early part of the year 1871.

Dr. Aitchison, surgeon-major in the Bengal Army, in a long paper, with thirty plates, containing the portraits of as many new species, gives us the result of his researches into the botany of the Curam Valley and its neighbourhood, during his march with the army under General Roberts to Cabool—a very interesting paper, when taken in reference to the boundaries of the two great works which treat of Southern Asiatic botany—viz. Hooker's 'Flora of British India' and Boissier's 'Flora Orientalis.'

In addition to these papers on descriptive botany, Mr. Bentham has given us several, which he has called *notes*, on the larger and more complicated natural orders, which he has worked up for the 'Genera Plantarum.' They are—

1. Notes on the Gamopetalous Orders belonging to the Campanulaceous and Oleaceous Group.
2. Notes on Orchidaceæ.
3. Notes on Cyperaceæ.
4. Notes on Gramineæ.

These notes, however, like those on Myrtaceæ and Compositæ, are philosophical treatises, in which he lays down the principles by which he has been governed in determining what characters shall be taken into consideration for limiting the tribes, sub-tribes, and genera.

Secondly: In the botanical part of the 'Annales des Sciences Naturelles,' although there are many papers of much excellence on the lower forms of vegetable life, there are few on the phanerogamia and higher cryptogams. On the mosses, however, there are several papers of very considerable interest by M. Emile Bescherelle, who has described a large number of new species from the French Antilles, and from the Reunion Islands. In the 'Botanische Zeitung' and 'Linnæa' there are also many papers describing new species of mosses from various extra-European countries by Dr. Carl Mueller, Professor S. O. Lindberg, Geheeb, and the late Ernest Hampe. Besides being indebted to these authors for their contributions to bryology, we have to thank M. Husnot for continuing his very unpretentious but useful periodical, the 'Revue Bryologique.' Dr. Braithwaite's work on the British mosses continues to make progress, but it will not render the publication of a new edition of 'Wilson's Bryologia Britannica' the less desirable.

Perhaps there are few more striking examples of the rapid strides which civilisation has made of late years in the more distant parts of the world, than the publication of the 'Scientist's Directory.' In this stout volume are recorded the many hundred names and addresses of all who are interested in the various branches of natural science, and who are desirous of collecting specimens of the natural history of the country in which they are residing, and of exchanging them for those of other countries. The arrangement of the directory is partly geographical and partly alphabetical, and the combination of these two arrangements makes its consultation very easy. For botanists who wish to study some particular group of plants, or the flora of some particular district, the 'Scientist's Directory' will be indispensable; as by its help he will be able to find out at once to whom he may address himself, with the greatest amount of probability of obtaining the material or information which he may want.

It would not be fitting for one in the year 1882, who is pretending to give an account of the progress of systematic botany, to omit all mention of that wonderful gallery of paintings which has just been presented to the Royal Gardens at Kew by Miss North. This gallery—the descriptive catalogue of which by Mr. Hemsley has already reached a second edition—contains the most exquisite sketches of the more strikingly beautiful features of the vegetation which exists in all the four quarters of the globe. All the paintings are from the brush of Miss North herself, and whether regarded as accurate representations of the plants which they profess to portray, or as objects of art, they are equally worthy of our admiration.

The following Reports and Papers were read:—

1. *Second Report of the Committee for the Investigation of the Natural History of Timor-laut.*—See Reports, p. 275.

2. *Report of the Committee for the Investigation of the Natural History of Socotra and the adjacent Highlands of Arabia and Somali Land.*—See Reports, p. 281.

3. *Report on the Record of Zoological Literature.*

4. *On the Brown Colouration of the Southampton Water. By* A. ANGELL, *Ph.D., F.C.S.*

The author showed that the peculiar colour of the Southampton estuarine water, which turns to a rusty brown tint in the summer of each year, is due solely to the presence of a small ciliated organism, *Peredinium fuscum*, which is classified by the best authorities amongst the ciliated protozoa, or microscopic animals. This position is generally accepted, but the author, seeing that they evolve oxygen, contain chlorophyl (plant colour-matter), have no mouth or opening of any kind, never contain foreign bodies, have cellulose walls, and, after death, give off an odour of decaying sea-weed, is of opinion that they are more plants than animals. He further sought to show that their presence is due to the large amount of sewage thrown into the river at and about Southampton. The seaward margin of the river water is distinctly mapped out by the brown colour, and the author noticed that this never leaves the estuarine basin, and pointed out that a measurement of the oscillations of this line provides a true index of the tidal motions, and shows that the water in the river is but very slowly, if at all, changed by the rise and fall of the tides. He showed it was an error to suppose that in tidal rivers and land-locked estuaries a fresh supply of water is given at every tide, and that, as a matter of fact, the time needed in which a single change in such waters as Southampton water will take place is dependent more upon the small flow of fresh water and surface evaporation than upon tidal influences. It is not, therefore, safe to pollute tidal waters with sewage; the impression that the filth goes out to sea with the tide is utterly false. Our peculiar brown colour gives us an indication by which we can learn that practically a change of the water of the Southampton Water, and therefore of all other similarly situated tidal river-mouths and land-locked estuarine basins, is but very slowly, if ever, effected by the tides. Enough filth, he said, is poured into the river to make it in hot weather a stinking abomination; but, in accordance with nature's provisions against such unnatural proceedings, a vast army of minute organisms is set to work, and the water is kept tolerably sweet. If it can be shown that this creature, which is barely visible to the naked eye, performs the chief function of plants—liberates oxygen—and is at the same time an animal and therefore carries on direct nitrification, it is indeed most wonderfully adapted, by this double set of powers, to keep our sewage-polluted waters as sweet as is possible. Notwithstanding the unsightly colour of *Peridinium fuscum*, we cannot afford to do without it in our river. When the day comes that the authorities of Southampton see fit to keep out the sewage now flowing into its waters so as to free them from such pollution, the *Peridinium fuscum*, no longer needed in such vast quantities, will retire into its normal position—become less obtrusive, and leave the water a pure translucent green.

5. *On the Distribution and Dates of Spring Migrants in Yorkshire, compared with West of England and Ireland. By* T. LISTER.

Not including very rare species which occasionally reach Britain, we may say of the Sylviidæ, Yorkshire is visited by all except the locally-distributed species

like the Dartford warbler (and the nest and eggs of this are reported by Mr. Dixon, late of Sheffield, in the Rivelin Valley).

The tabulated list appended gives names, dates, and comparative occurrence of migrants in Yorkshire. We need not particularise them further than to make a few comparisons with other parts of the kingdom. The author was struck, during the visits of the British Association to the south-west of England and Ireland, by personal observation and conversation with authorities like the Rev. G. Robinson, a writer on the ornithology of North Ireland, and Mr. J. J. Watters of Dublin, author of 'Birds of Ireland,' with the common occurrence of some of our migrants and the scarcity or absence of others.

Tabulated List of Spring Migrants.

	1872.	1881.	Average for 10 years.	Average departure for 10 years.	Relative occurrence.
Cuckoo (*Cuculus canorus*)	March 19	April 14	April 14	Aug. 25	very common
2nd date . .	April 2				
Swallow (*Hirundo rustica*)	March 19	April 11	April 10	Oct. 15	numerous
2nd date . .	April 1				
Chiff-chaff (*Sylvia rufa*)	March 27	March 18	April 2	Oct. 4	common
Sand martin (*H. riparia*)	April 9	April 13	April 9	Sep. 20	locally common
Wheatear (*Saxicola Œnanthæ*)	April 9	March 25	March 29	Sep. 30	common
Willow-warbler (*S. trochilus*)	April 11	April 11	April 10	Sep. 26	abundant
Whinchat (*S. rubetia*) .	April 11	April 23	April 20	Sep. 22	numerous
Redstart (*Ruticilla phœnicurus*)	April 16	April 13	April 14	Sep. 20	common
Ray's wagtail (*Motacilla Rayii*)	April 16	April 11	April 13	Sep. 14	common
Tree-pipit (*Anthus arboreus*)	April 17	April 11	April 15	Sep. 22	very common
Whitethroat (*S. cinerea*)	April 17	April 15	April 25	Sep. 27	numerous
Land-rail (*Crex pratensis*)	April 19	April 28	April 10	Oct. 5	numerous
Grasshopper-warbler (*S. locustella*)	April 22	April 16	April 30	Sep. 5	common
Martin (*H. urbica*)	April 23	April 16	April 14	Oct. 12	common
Sedge-warbler (*Salicaria phragmitis*)	April 25	April 27	April 24	Aug. 31	numerous
Blackcap (*S. atracapilla*)	April 27	April 18	April 22	Oct. 10	common
Lesser whitethroat (*S. curruca*)	April 28	May 2	May 4	Sep. 15	common
Nightingale (*Philomela luscinia*)	May 1	April 28	May 8	July 27	moderately occurring
Spotted or grey flycatcher (*Muscicapa grisola*)	May 1	April 30	May 14	Sep. 2	common
Pied flycatcher (*M. atracapilla*)	May 1	April 18	April 22	Sep. 1	locally common
Garden-warbler (*S. hortensis*)	May 3	May 5	May 6	Sep. 10	common
Wood-warbler (*S. sibilatrix*)	May 3	April 27	May 3	Sep. 18	common
Night-jar (*Caprimulgus Europæus*)	May 3	May 21	May 18	Aug. 30	locally common
Swift (*Cypselus apus*) . .	May 13	May 3	May 8	Aug. 15	locally common

In Ireland the wheatear, chiff-chaff, cuckoo, willow-warbler, and land-rail were reported as common; the ring-ousel, sand-piper, sedge-warbler, and spotted fly-catcher occur locally; the garden-warbler very scarce; the black-cap two or three occurrences; the whinchat scarce, the redstart, Ray's wagtail, grasshopper-warbler, rarely noted, while the nightingale, tree-pipit, lesser-whitethroat, pied flycatcher, and wood-warbler were not recorded in Ireland. The swallow tribes were numerous there.

All the migrants in my list are found in the southern, and in most of the eastern and western counties of England. The pied flycatcher is exceptionally rare; it is recorded by Sterland and Whittaker in Notts, but rare; one in Derbyshire, one Leicestershire, one Kent, one Cornwall, a few in Dorset, Sussex, and Norfolk. In this part of Yorkshire, of which Barnsley is the centre, it is found at Wharncliffe, Cannon Hall, and Wentworth Castle parks; in Wharfdale, Westmoreland, a few in North Yorkshire, rare about York. The nightingale, one of the migrants not found in Ireland, rarely crosses the Welsh border, or those of Devon and Cornwall. It occurs on all sides of Barnsley yearly, about Wakefield, Leeds, Pontefract more rarely, and, according to Mr. J. Backhouse, specimens have occasionally occurred near York. The grasshopper-warbler, scarce in some districts, may be found pretty numerous in our South Yorkshire woods and hedgerows, rich in the families of our spring warblers.

An earlier date of cuckoo, seen and heard at Melton-on-the-Hill, March 12, was reported; we had no opportunity to test the statement. The cuckoo and swallow seen by T. Dymond, Esq., and others at Burntwood Hall, March 10, we can rely upon. We have never known them before in this district in March. There have been singular contrasts this season to former years. The two white-throats, grasshopper-warbler, night-jar, spotted flycatcher, and whinchat were seven or ten days before their average time; the wheatear, land-rail, pied flycatcher and martin (as reported in this part), are about a week behind their time. The spring migrants, as noted in our local excursions, and with some of the 'Yorkshire Naturalist Union's' rambles this season, have been observed in considerable numbers. The well-wooded tracts of South and West Yorkshire, diversified with cultivated lands, streams, and moorland hills, form favourable haunts for our summer warblers. Other migrants, as ring-ousels, on our moors; reed-warblers among marshes and reedy pools; sand-pipers, by moorland streams; and white wagtails scarce, have not had data regularly recorded.

SATURDAY, AUGUST 26.

The Department did not meet.

MONDAY, AUGUST 28.

1. *Report of the Committee for arranging for the occupation of a Table at the Zoological Station at Naples.*—See Reports, p. 288.

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2. *Report of the Committee for aiding in the maintenance of the Scottish Zoological Station.*—See Reports, p. 282.

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3. *Report on the Migration of Birds.*—See Reports, p. 283.

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4. *The injurious Parasites of Egypt in relation to Water-Drinking. By* Dr. COBBOLD, *F.R.S.*

The author stated that the most dangerous parasites were *Bilharzia hæmatobia* and *Anchylostoma duodenale.* To avoid infection by the larvæ the following rules were recommended:—

1. To select for drinking purposes, whenever procurable, either deep well water, or water from a spring collected at or near its source.

2. To avoid the use of stagnant water of any kind, especially that procured from tanks or shallow pools.

3. If the only water available for drinking purposes has been obtained from a doubtful source, it must either be thoroughly filtered or boiled: merely straining through muslin or other of the coarser kinds of filter is useless. On excursions or shooting expeditions a pocket filter must be carried.

4. Avoid partaking of all salads made with vegetables grown either in market gardens or in open situations frequented by natives of uncleanly habits. Lettuces, water-cresses, and other uncooked vegetables, even when they are known to have been cultivated in favourable situations, require to be carefully washed with clean water before use. Only spring water, well water, filtered water, boiled water, and distilled water can be pronounced as absolutely safe: springs near human habitations are liable to become contaminated.[1]

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5. *On a new Principle affecting the systematic Distribution of the* Torpedinidæ, *and on the probable occurrence of the* T. occidentalis *(Storer) on the British Coast. By* E. DU BOIS-REYMOND, *F.R.S., Professor of Physiology in the University of Berlin.*

Professor Gustavus Fritsch, who is at the head of the biological department of my physiological laboratory, is engaged in a series of researches on electric fishes, which he has pursued, since last autumn, in Egypt, Asia Minor, and on the shores of the Mediterranean, at the cost of the Humboldt Foundation for Natural Science and Travels, dependent on the Berlin Academy of Sciences. Among Professor Fritsch's results there is one which, highly remarkable in itself, seems to me particularly calculated to interest British zoologists, and I therefore venture to ay before the Section a brief abstract of this part of his work.

The researches of Professor Babuchin of Moscow, on the development of the electric organs of the torpedo, have established beyond a doubt that these organs are formed by the metamorphosis of striated muscle, and that, once formed, they increase in size only by the growth of the columns or prisms of which they consist, and of the transverse septa of these columns, never by the formation of new columns and septa, or of new electric elements. Setting aside individual variation the number of columns, therefore, is the same in young and in adult specimens.

The latter fact had already been stated, many years ago, by delle Chiaie of Naples, and he had arrived at the same conclusion as Professor Babuchin. Later on, the preformation of electric elements was impugned by Professor Valentin; but Rudolph Wagner, with the assistance of Professor Leuckart, then one of his pupils, proved delle Chiaie's statement to be correct, for he found about the same number of columns in the fœtus of torpedo and in the adult fish. As the law of the preformation of electric elements was first established by means of a census of the columns in young and adult specimens by delle Chiaie, and afterwards deduced from embryological facts, and, as it will be seen, generalised by Professor Babuchin, it appears proper to style it delle Chiaie's and Babuchin's law.

Professor Babuchin, by embryological investigation, has shown the same law to apply to the imperfect electric organs of the common ray, only that these organs are formed of striated muscle which in its development has reached maturity, whilst the organs of torpedo are formed of muscle in an embryonic state.

[1] Full reports of this paper are given in *Nature,* September 14, and in the *British Medical Journal,* September 16, 1882.

In spite of Professor Babuchin's and of Dr. Sachs' exertions, the development of Malopterurus and of Gymnotus unfortunately is still wrapped in mystery. Professor Babuchin, however, confidently extends his law to Malopterurus, as the size of Bilharz' electric plates varies in proportion to the size of the fish.

In my work on Gymnotus,[1] by combining the results of former observers with those of the lamented Dr. Sachs, I have proved the number of columns to be the same in large and in small specimens, again taking into account individual variation. Professor Fritsch has confirmed this statement by a new and careful census of the columns in several specimens widely differing in size.[2]

It is not my intention on this occasion to enter upon the many important inferences which may be drawn from delle Chiaie's and Babuchin's law. This law, indeed, has become a leading fact in the physiology as well as in the embryology of the electric organs. For instance, an obvious conclusion from it is the following. The number of electric plates remaining the same, and their thickness only increasing with the size of the fish, whilst the electromotive force of the discharge also increases, the difference of potential engendered by every plate is evidently proportionate to its thickness. Now, as the difference of potential does not depend upon the size of the bodies by whose reciprocal action it is produced, we are unavoidably led to conclude that in a thicker electric plate there is a repetition, and consequently a multiplication, of the difference of potential in proportion to its thickness.

But my wish here is to direct the attention of the Section to the part which delle Chiaie's and Babuchin's law seems destined to play in the systematic distribution of the Torpedinidæ. According to it, the number of columns in the electric organs of a species of Torpedinidæ, is, from a certain stage of its development, a given one. This number may be the same, or nearly the same, in distinct species of Torpedinidæ. But if, in two specimens which do not otherwise show very marked specific characters, the number of columns differs more than the range of individual variation fairly permits, the specimens ought to be pronounced specifically distinct. In other words, the average number of columns ought, henceforward, to form part of the *diagnosis* of a species of Torpedinidæ.

Hitherto this point has been entirely overlooked by zoologists. Elaborate papers were published on the system of the Torpedinidæ, in which the number of the columns is not even mentioned. The whole literature on torpedo from Hunter's time down to Professor Fritsch's new researches, did not comprise more than sixteen enumerations of columns, on only fourteen specimens.[3] They were all of them made, as it was understood at the time, on common European species, *T. marmorata*, *ocellata*, *Galvanii*, excepting one, by Professor Henle, on his *Narcine* (now *Astrape*) *dipterygia*, from the South Sea. This species offered the unusually small number of 130 columns. The other species yielded numbers from about 300 to about 500, excepting, however, one of two very large torpedines, of 4 ft. in length and 50 lbs. weight, which in 1773 were caught off Torbay, and examined by the illustrious John Hunter. He counted 1,182 columns in one of their organs. As he had counted 470 columns in one of the organs of an 18-inch specimen of the common torpedo, and as he took for granted that these huge torpedines were simply older individuals of the same species, he by this single observation was led to the erroneous conclusion that the columns increase, 'not only in size but in number, during the growth of the animal, new ones forming perhaps every year on the exterior edge, as there they are much the smallest.' This process, he adds, may be similar to the formation of new teeth in the human jaw, as it increases; and for more than sixty years this bold assumption of Hunter's has reigned undisputed in all the text-books of zoology and physiology.

Hunter, however, could not have chosen a less felicitous illustration. After a certain stage of development is over, new columns form as little in the electric organ of torpedo as new teeth in the human jaw. The true conclusion to be drawn

[1] Dr. Carl Sachs' *Untersuchungen am Zitteraal, Gymnotus electricus, nach seinem Tode bearbeitet von* E. du Bois-Reymond. Mit zwei Abhandlungen von G. Fritsch. Leipzig, 1881, pp. 31, 32.

[2] *L. c.* pp. 361, 393.

[3] *L. c.* p. 401.

from the enumerations of columns hitherto extant is that which I maintained in my book on Gymnotus, viz. that *N. dipterygia* proves a good species also by the new test of the number of columns, whereby the value of this test is confirmed; and that the two large specimens of Torbay belonged to another species than the common European Torpedinidæ. They may have been, as I ventured to surmise, remnants of the *T. gigantea*, whose relics, of about the same size as Hunter's fish, occur in the Eocene strata of Monte Bolca, and show that even in those remote geological times Nature had solved the problem of building a most powerful electrical machine out of the common materials of the animal tissues.

This conclusion has become the starting-point of Professor Fritsch's researches on the system of Torpedinidæ, made at Alexandria, Suez, Smyrna, Naples, and Trieste. Michele Girardi, who ten years after Hunter published some observations on the electric organs of torpedo, stated that the number of columns is not always the same in both organs. But previous to Professor Fritsch nobody had even thought of inquiring whether the number of columns is the same in the dorsal and in the ventral surface of the organs. According to Professor Fritsch, the ventral surface offers the greater number, although the difference decreases with the accuracy of the method employed.

Professor Fritsch, by many careful enumerations, first confirmed delle Chiaie's, Rudolph Wagner's, and Professor Leuckart's statement regarding the equality of the numbers of columns yielded by small and by large specimens of the same species. He then ascertained that the number of columns in one organ of *T. marmorata* and *ocellata* varies from 400 to 500; that *T. marmorata* probably has, on the average, a few columns more than *T. ocellata*; and that the number of columns is much the same in *T. panthera*, Ehrbg., from the Red Sea, and also in *N. brasiliensis*. A variety of *T. marmorata* occurs at Alexandria, Naples, and Trieste, which Professor Fritsch calls *annulata* on account of dark, ring-shaped spots on its back and tail; this variety, which perhaps is identical with the ill-defined *T. Nobiliana*, Bonaparte, has a greater number of columns than the common *T. marmorata*, viz. from 500 to 600.

These results seemed more and more to confirm the view that Hunter's large torpedines were a new species. On his way home Professor Fritsch visited the Zoological Museum at Vienna, hoping to meet there with a specimen of the fossil *T. gigantea* of Monte Bolca. In this expectation he was deceived, but the key to the enigma of Hunter's big fish awaited him in another shape.

The director of the museum, Professor Steindachner, told him that he had brought from America the two only specimens existing in Europe of a very remarkable species of torpedo, and they were still in his possession. This was the *T. occidentalis* of David Humphreys Storer of Boston, which that distinguished ichthyologist described forty years ago, but which is not mentioned in otherwise very complete accounts of the tribe, and in Dr. Gunther's Catalogue of the Fishes of the British Museum its name only is quoted in a footnote. At certain periods large numbers of *T. occidentalis* run ashore on the sandy beach of Cape Cod. It is by far the largest electric fish, as it attains a length of five feet and a weight of 200 pounds. The largest gymnoti of the Amazon are said by old Monteiro to attain forty pounds weight. Its electric stroke is formidable. Captain Nathaniel E. Atwood of Provincetown, to whom science is indebted for the first notice of the fish, relates that several times he was 'thrown upon the ground by it as quick if he had been knocked down with an axe.'

I need not dwell here on other peculiarities of the *T. occidentalis*, a detailed account of which is found in Storer's papers. The most important specific character of the new species, however, evaded Storer's attention, and it fell to Professor Fritsch's lot to detect it forty years later in the Vienna Museum. Professor Steindachner kindly permitted the skin to be removed from one of the organs of each of his fish, and Professor Fritsch found nearly the same number of columns as Hunter in his large torpedo, viz. 1,037 columns in the better preserved specimen of the two, and also about 1,000 in the other.

There can hardly be any doubt, after this, that Hunter's fish were specimens of *T. occidentalis*, drifted, we may suppose, to the English coast by the Gulf-stream.

Delle Chiaie's and Babuchin's law has thus proved the means of solving a zoological puzzle of a hundred years' standing; and surely this result may serve to recommend it to the attention of those interested in this subject.

I have been so fortunate as to meet with two more instances of the probable capture of *T. occidentalis* in the records of British natural history. The well-known naturalist, Colonel Montagu, who died in 1815, relates that a torpedo weighing about a hundred pounds, twice as heavy as Hunter's fish, was found dead on a turbot-hook off Tenby. Even the oldest fishermen did not know the creature, which proves the case to be a very rare one. In the year 1840, William Thompson, Vice-President of the Natural History Society of Belfast, saw in the Museum of the Dublin College of Surgeons the cast of a torpedo thirty-eight inches long and twenty-eight inches broad, which had been caught off Dublin in 1830. I know of no instance of a European torpedo approaching this size. The coincidence with Hunter's observation was not perceived in either case, and I need hardly add that the columns were not numbered.

However rare the event may be, it is exceedingly improbable that these three cases—Hunter's, Montagu's, and William Thompson's, separated from one another by an interval of about thirty years—should have been, and remain, the only ones of their kind. And now my aim, in bringing these facts before the Section will, I trust, be apparent. I venture to express a wish that those British zoologists in whose power it may be may issue instructions to the fishermen, more particularly on the south-western coast of England, to the effect that if, in one of their expeditions, they should meet with a huge flat fish, similar to a ray, but of circular instead of rhombic shape, and endowed during life with a power of benumbing the hand that grasps it, they are requested to preserve such fish with the utmost care, and to forward it as speedily as possible to the nearest scientific station. It is needless to indicate the further course to be held. The specimen should be compared with Storer's description of his *T. occidentalis*, and above all, the columns in its electric organs numbered according to the rules laid down by Professor Fritsch.

Since Henle's paper on *N. dipterygia*, this species has been detached from *N. brasiliensis*, and annexed to the genus *Astrape* as *A. capensis*. In my Preliminary Report on Professor Fritsch's Results, read before the Berlin Academy,[1] I expressed an opinion that *A. capensis* would present a number of columns about as small as *A. dipterygia*, and so it proved, a specimen which Professor Peters readily placed at Professor Fritsch's disposal, showing only 146 columns. On the other hand, *T. californica*, which bears a great resemblance to *T. occidentalis*, has, like this species, nearly 1,000 columns.

The value of the new character of Torpedinidæ being thus fully established, Professor Fritsch proceeded to test by it every species he could lay his hands upon, by taking the census of its columns. After having gone over the specimens of the Berlin Museum, he came to London a few weeks ago, and owing to the extreme kindness of Professor Owen and Dr. Günther, he was allowed to continue his work in the splendid collection of the British Museum. Of the results at which he arrived, I shall only mention one here, leaving the other for his own publication. A single glance at the unique and typical specimen of the *T. hebetans*, Lowe, from Madeira, enabled him to predict, from a certain conformity of habitus with *T. occidentalis* and *californica*, that this species, although not quite ten inches long, would present an equally large number of columns, and he eventually counted 1,025 of them in one of the organs.

He also saw in the Museum of the College of Surgeons a relic of one of Hunter's specimens, exhibiting the brain and the electrical nerves; but although in a wonderful state of preservation after so many years, this interesting preparation was of no use to him for his present purpose, as one of the organs had been entirely, and the other partially removed.

[1] *Vorläufiger Bericht über die von Professor Gustav Fritsch in Ægypten und am Mittelmeer angestellten neuen Untersuchungen an elektrischen Fischen.* Zweite Hälfte. Sitzungsberichte der Kgl. Preuss. Akademie der Wissenschaften zu Berlin, 4. Mai 1882; St. xxiii. p. 489.

6. *Preliminary Note on* Cephalodiscus, *a new form allied to Prof. Allman's* Rhabdopleura—*dredged in H.M.S. 'Challenger.'*[1] *By* Professor McIntosh, *F.R.S.*

This peculiar form was dredged at Station 311 (in the Strait of Magellan), and at first sight resembles a somewhat massive sea-weed, to which the *cœnœcium* is allied in consistence, while the whole surface is hispid with long spinous processes of the same tissue. This *cœnœcium* is secreted by the minute inhabitants, which, though quite free, are closely allied in structure to *Rhabdopleura*, an opinion independently arrived at by Professors Allman and Busk, who kindly requested the author (who had lately received the specimens from Mr. Murray, Director of the *Challenger* Commission) to continue the description.

The *cœnœcium* consists of thickish, semi-transparent, irregularly moulded branches, ranging from about 3 mm. to upwards of 5 mm. in diameter, and forming arborescent tufts, which apparently have been fixed to submarine bodies, such as stones, sponges, &c., both by the ends and sides. The whole is permeated by irregular canals and cavities, which open on the surface, often near the bases of the spines. In these cavities are found the free polypides, often in groups, and numerous large ova.

Each adult has a somewhat bean-shaped body, with a pedicle posteriorly-continuous with the ventral surface, the whole measuring about 2 mm. The anterior end is rounded; indeed often very prominent from the contained ova, two of which are conspicuous. The ventral surface of this region bears two very large eyes. The body is bulbous posteriorly. In front of the mouth a great buccal disc overlaps the neighbouring parts, and is probably the chief agent in secreting the cœnœcium. In front of it are twelve[2] long and richly pinnate, branchial, or tentacular organs, which arise from a base devoid of a web, and each of which has a peculiarly enlarged tip. Behind the mouth is a broad apron-like membranous lamella. The body-wall is formed of a thin hypodermic and an elastic layer, bounded by longitudinal fibres internally. The pedicle has the same dermal coverings as the body, and internally consists of strong longitudinal muscular fibres, continued from the ventral surface anteriorly.

The mouth opens above the buccal shield, at the upper margin of the membranous lamella, and leads into a simple alimentary canal, which bends forward at the posterior end of the body, and proceeds along the dorsum, to terminate in the anus on the prominent anterior end of the body. The food which enters the mouth must pass between the great flattened shield, on the one hand, and the membranous post-oral lamella, on the other.

Immediately above the eyes are the two greatly developed ova, and towards the middle of the body several smaller ova These seem to arise from a spot nearly identical with the 'remarkable organ' in Pedicellina, and to be homologous with a double organ of similar nature in the embryo of *Loxosoma*. When discharged these ova are attached to the wall of the cavities of the *cœnœcium* by a process or pedicle of the hyaline investment. Their size is remarkable.

In addition to the foregoing mode of propagation, very active budding takes place at the tip of the pedicle of the adult, the buds being found in all stages, from a minute rounded or clavate process up to a fairly formed specimen. Even in the earlier stages the buccal shield is conspicuous. The branchial or tentacular plumes first appear as globular papillæ on the dorsum of the shield. Two or three buds occur on many specimens. This new form will open up interesting comparisons with *Doliolum* and others having buds on processes.

The occurrence of these large ova anteriorly, and the numerous buds on the tip of the pedicle posteriorly, bears out Professor Allman's objection to Oscar Schmidt's view that the apparent buds in *Loxosoma* are really eggs detached from the ovary and developed on the body of the parent.

[1] Published by permission of the Lords Commissioners of the Treasury. Published *in extenso* in *Annals of Nat. Hist.*, November 1882.

[2] Hence the name of the species—*dodecalophus*.

Cephalodiscus, n.g.

Cœnœcium, consisting of a massive irregularly-branched fucoid secretion, hispid with long spines of the same tissue, and honeycombed throughout by irregular apertures, channels, and spaces in which the separate and independent polypides occur.

Lophophore, richly plumose, with an enormous buccal shield and oral lamella, the mouth opening between them. Anus on the anterior dorsal prominence behind the plumes. Two very large eyes abutting on the ovaries. The homologue of the funiculus is short and quite free at the end, and, moreover, serves as the only site for the buds.

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7. *On an Instructional System of Arrangement in Provincial Museums.* *By* F. T. Mott, *F.R.G.S.*

DEPARTMENT OF ANTHROPOLOGY.

Chairman of the Department—Professor W. Boyd Dawkins, M.A., F.R.S., F.S.A., F.G.S. (Vice-President of the Section).

THURSDAY, AUGUST 24.

The Chairman delivered the following Address:—

On the Present Phase of the Antiquity of Man.

In taking the chair in this department of the biological section of the British Association, two courses lie open before me. I might give an address which should be a history of the progress of anthropology during the last year, or I might devote myself to some special branch. The swift development of our young and rapidly growing science, which embraces within its scope all that is known, not merely about man, but about his environment, in present and past times, renders the first and more ambitious course peculiarly difficult to one, like myself, labouring under the pressure of many avocations. I am therefore driven to adopt the second and the easier, by choosing a subject with which I am familiar, and which appears to me to be appropriate in this place of meeting. I propose to place before you the present phase of the inquiry into the antiquity of man, and to point out what we know of the conditions of life—though our knowledge of them is imperfect and fragmentary—under which man has appeared in the Old and in the New Worlds. The rudely chipped implements left by the primeval hunters in the beds of gravel of Hampshire and Wiltshire, and along the shores of Southampton Water and elsewhere, are eloquent of the presence of man in this district at a time when there was no Southampton Water and the elephant and the reindeer wandered over the site of this busy mart for ships; when the Isle of Wight was not an island and the River-drift hunter could walk across from Portsmouth to Cowes, with no obstacle excepting that offered by the rivers and morasses. I propose to enter upon the labours of Prestwich, Evans, Stevens and Blackmore, Codrington, Read, Brown, and other investigators in this country, and to combine the results of their inquiries with those in other countries, and with some observations of my own which I was able to make in 1880, during my visit to the United States.

The Limitation of the Inquiry.

The most striking feature in the study of the Tertiary period is the gradual and orderly succession of higher types of Mammalia, so well-defined and so orderly, that I have used it as a basis for the classification of the Tertiary period. We find the placental mammals becoming more and more specialised as we approach the frontier of history. The living orders appear in the Eocene, the living genera in the Meiocene, a few living species in the Pleiocene, and the rest in the Pleistocene. The characteristics of this evolution of living forms may be summed up in the following table:—

Definition of Tertiary Period by Placental Land Mammals.

VI. Historic; in which the events are recorded in history	Events included in history	Founded on discoveries, documents, refuse-heaps, caves, tombs
V. Prehistoric; in which domestic animals and cultivated fruits appear	Man abundant; domestic animals, cultivated fruits, spinning, weaving, pottery-making, mining, commerce; the neolithic, bronze, and iron stages of culture	Camps, habitations, tombs, refuse-heaps, surface accumulations, caves, alluvia, peat-bogs, submarine forests, raised beaches
IV. Pleistocene; in which living species of placental mammals are more abundant than the extinct	Man appears; *Anthropidæ*; the palæolithic hunter; living species abundant	Refuse-heaps, contents of caves, river-deposits, submarine forests, boulder-clay, moraines, marine sands, and shingle
III. Pleiocene; in which living species of placental mammals appear	Living species appear; apes, *Simiadæ*, in Southern Europe	Fresh-water and marine strata; volcanic débris (Auvergne)
II. Meiocene; in which the alliance between living and placental mammals is more close than before	Living genera appear; apes, *Simiadæ*, in Europe and North America	Fresh-water and marine strata; volcanic débris (Auvergne); lignites
I. Eocene; in which the placental mammals now on earth were represented by allied forms belonging to existing orders and families	Living orders and families appear; lemurs (*Lemuridæ*) in Europe and North America	Fresh-water and marine strata; lignites

The orders, families, genera, and species in the above table, when traced forward in time, fall into the shape of a genealogical tree, with its trunk hidden in the Secondary period, and its branchlets (the living species) passing upwards from the Pleiocene, a tree of life, with living Mammalia for its fruit and foliage. Were the extinct species taken into account, it would be seen that they fill up the intervals separating one living form from another, and that they too grow more and more like the living forms as they approach nearer to the present day. It must be remembered that in the above definitions the fossil marsupials are purposely ignored because they began their specialisation in the Secondary period, and had arrived in the Eocene at the stage which is marked by the presence of a living genus—the opossum (*Didelphys*).

It will be seen, from the examination of the above table, that our inquiry into the antiquity of man is limited to the last four of the divisions. The most specialised of all animals cannot be looked for until the higher Mammalia by which he is now surrounded were alive. We cannot imagine him in the Eocene age, at a time when animal life was not sufficiently differentiated to present us with any living genera of placental mammals. Nor is there any probability of his having appeared on the earth in the Meiocene, because of the absence of higher placental mammals belonging to living species. It is most unlikely that man should have belonged to a fauna in which no other living species of mammal was present. He belongs to a more advanced stage of evolution than the mid-Meiocene of Thenay, as may be seen by a reference to the preceding table. Up to this time the evolution of the animal kingdom had advanced no farther than the Simiadæ in the direction of man, and the apes then haunting the forests of Italy, France, and Germany represent the highest type of those on the earth.

We may also look at the question from another point of view. If man were upon the earth in the Meiocene age, it is incredible that he should not have become something else in the long lapse of ages, and during the changes in the conditions of life by which all the Meiocene land Mammalia have been so profoundly affected, that they have been either exterminated, or have assumed new forms. It is impossible to believe that man should have been an exception to the law of change, to which all the higher Mammalia have been subjected since the Meiocene age.

Nor in the succeeding Pleiocene age can we expect to find man upon the earth, because of the very few living species of placental mammals then alive. The evidence brought forward by Professor Capellini, in favour of Pleiocene man in Italy, seems both to me and to Dr. Evans unsatisfactory, and that advanced by Professor Whitney in support of the existence of Pleiocene man in North America, cannot in my opinion be maintained. It is not until we arrive at the succeeding stage, or the Pleistocene, when living species of Mammalia begin to abound, that we meet with indisputable traces of the presence of man on the earth.

The Pleistocene Period.

As a preliminary to our inquiry we must first of all define what is meant by the Pleistocene Period. It is the equivalent of the Quaternary of the French, and the Postpleiocene of the older works of Lyell, and it includes all the phenomena known in latitudes outside the Arctic Circle, where ice no longer is to be found, under the name of glacial and inter-glacial. It is characterised in Europe, as I have pointed out in my work on 'Early Man in Britain,' by the arrival of living species, which may be conveniently divided into five groups, according to their present habitats. The first consists of those now found in the temperate zones of Europe, Asia, and North America. It includes the following animals:—

Mole, musk shrew, common shrew, mouse, beaver, hare, pika, pouched marmot, water-vole, red field-vole, short-tailed field-vole, continental field-vole, lynx, wild cat, wolf, fox, marten, ermine, stoat, otter, brown bear, grisly bear, badger, horse, bison, urus, saiga antelope, stag, roe, fallow-deer, wild boar.

The second consists of animals of arctic habit:—

Russian vole, Norwegian lemming, arctic lemming, varying hare, musk sheep, reindeer, arctic fox, glutton.

The third is composed of those which enjoy the cold climate of mountains:—

The snowy vole, Alpine marmot, chamois, and ibex.

These animals invaded Europe from Asia, and as the cold increased the temperate group found their way into Southern Europe and Northern Africa, while the arctic division pushed as far south as the Alps and Pyrenees.

The fourth group of invading forms is represented by animals now only found in warm countries:—

Porcupine, lion, panther, African lynx, Caffre cat, spotted hyena, striped hyena, and African elephant.

This group of animals is found as far to the north as Yorkshire, and as far to the

west as Ireland. Among the southern animals, too, must be reckoned the hippopotamus, which lived as far north as Britain in the Pleiocene age, and in the Pleistocene occurs in caves and river-deposits, in intimate association with some arctic species, such as the reindeer.

The fifth group is composed of extinct species, hitherto unknown in Europe in the Pleistocene age, such as—

The straight-tusked elephant, mammoth, the pigmy elephants, woolly and small-nosed rhinoceroses, the Irish elk, pigmy hippopotamus, and the cave bear.

The question as to which of these groups the River-drift man belongs must be deferred till we can take a survey of the evidence elsewhere.

The early Pleistocene division is characterised by the presence of the temperate and southern species in Britain; the middle stage by the presence of the arctic, but not in full force; and the late Pleistocene by the abundance of arctic animals, not only in Britain, but on the Continent as far as the Alps and Pyrenees, and the lower valley of the Danube.

The Early Pleistocene Forest and Mammals of East Anglia.

The first view which we get of the Pleistocene Mammalia in this country is offered by the accumulations associated with the buried forest of East Anglia. It extends for more than 40 miles along the shores of Norfolk and Suffolk, from Cromer to Kessingland, passing into the cliff on the one hand and beneath the sea on the other. The forest was mainly composed of sombre Scotch firs and dark clustering yews, relieved in the summer by the lighter tinted foliage of the spruce and the oak, and in the winter by the silvery gleam of the birches, that clustered thickly with the alders in the marshes, and stood out from a dense undergrowth of sloes and hazels. Among the animals living in this forest of the North Sea were species which haunted the valleys of the Upper Seine at the time, such as the southern elephant, the Etruscan rhinoceros, the deer of the Carnutes, extinct horses, and the large extinct beaver. There were in addition the shaggy-maned mammoth, the straight-tusked elephant, and the big-nosed rhinoceros. The stag, the roe, the Irish elk, were in the glades, Sedgwick's deer with its many-pointed antlers, the verticorn deer, and the gigantic urus. The undergrowth formed a covert for the wild boar, and for beasts of prey, many in species and formidable in numbers: the cave bear, the hugest of its kind, the sabre-toothed lion, the wolf, the fox, and the wolverine. Among the smaller animals were to be noted the musk shrew, the common shrew, and a vole. In the trees were squirrels. Underfoot the moles raised their hillocks of earth, and from between the lofty fronds of the king-fern beavers were to be seen building their lodges, and the hippopotamus as he emerged from the water and disappeared in the forest. Out of thirty species identified, no less than seventeen are living in some part of the world, and we have there obviously the stage in the evolution of mammalian life when the living species were becoming more abundant than the extinct. We may note, too, the absence of arctic animals in this fauna, more particularly of the reindeer.

The presence of these animals in Norfolk and Suffolk implies that at this time Britain was united to the Continent, and the presence of fossil species found in France indicates a southern extension of land in the direction of the Straits of Dover. The forest covered a large portion of the area of the North Sea, and in all probability the Atlantic seaboard was then at the 100-fathom line of the west coast of Ireland.

No traces of man have as yet been discovered in these deposits, although the large percentage of living species of higher Mammalia indicates that the geological clock had struck the hour when he may be looked for.

The Appearance of the River-drift Hunter at Crayford and Erith.

The living species in the forest-bed are to be looked upon as an advanced guard of a great migration of Asiatic and African species, finding their way into North-western Europe, over the plains of Russia, and over barriers of land connecting

Northern Africa with Spain by way of Gibraltar, and with Italy by way of Malta and Sicily.[1]

In the course of time other living species followed, and the extinct species became more rare. In the deposits, for instance, of the ancient Thames, at Ilford and Grays Thurrock in Essex, and at Erith and Crayford in Kent, out of twenty-six species, six only belong to extinct forms—the new-comers comprising the lion, wild cat, spotted hyena, and otter, the bison, and the musk sheep. A flint flake discovered by the Rev. Osmund Fisher, at Crayford, and a second discovered by Messrs. Cheadle and Woodward, at Erith, prove that man was present in the valley of the Thames at this time; while the more recent discoveries of Mr. Flaxman Spurrell indicate the very spots where the palæolithic hunter made his implements, and prove that he used implements of the River-drift type, so widely distributed over the surface of the earth. The arctic animals at this time were present, but not in full force, in Southern Britain, and the innumerable reindeer which characterise the later deposits of the Pleistocene age had not, so far as we know, taken possession of the valley of the Thames.

To what stage in the Pleistocene period are we to refer these traces of the River-drift hunter? The only answer which I am able to give is that the associated animals are intermediate between the Forest-bed group and that which characterises the late Pleistocene division in the region extending from the Alps and the Pyrenees as far north as Yorkshire. Nor am I able to form an opinion about their relation to the submergence of Middle or Northern Britain under the waves of the glacial sea. They are quite as likely to be pre- as post- glacial.

The Relation of the River-drift Hunter of the Late Pleistocene to the Glacial Submergence.

The rudely chipped implements of the River-drift hunter lie scattered through the late Pleistocene river deposits in Southern and Eastern England in enormous abundance, and as a rule in association with the remains of animals of arctic and of warm habit, as well as some or other of the extinct species of reindeer and hippopotamus, along with mammoth and woolly rhinoceros. What is their relation to the submergence of the land and the lowness of the temperature, which combined together have resulted in the local phenomena known as glacial and interglacial?

The geographical change in Northern Europe at the close of the Forest-bed age was very great. The forest of the North Sea sank beneath the waves, and Britain was depressed to a depth of no less than 2,300 feet in the Welsh mountains, and was reduced to an archipelago of islands, composed of what are now the higher lands. The area of the English Channel also was depressed, and the 'silver streak' was somewhat wider than it is now, as is proved by the raised beach at Brighton, at Bracklesham, and elsewhere, which marks the sea line of the largest island of the archipelago, the southern island, as it may be termed, the northern shores of which extended along a line passing from Bristol to London. The northern shore of the Continent at this time extended eastwards from Abbeville north of the Erzgebirge, through Saxony and Poland, into the middle of Russia, Scandinavia being an island from which the glaciers descended into the sea.

This geographical change was accompanied by a corresponding change in climate. Glaciers descended from the higher mountains to the sea-level, and icebergs, melting as they passed southwards, deposited their burdens of clay, sand, and erratics, which occupy such a wide area in the portions then submerged of Britain and the Continent.

This depression was followed by a re-elevation, by which the British isles again formed part of the Continent, and all the large tract of country within the 100-fathom line again became the feeding-grounds of the late Pleistocene Mammalia.

An appeal to the animals associated with the River-drift implements will not help us to fix the exact relation of man to these changes, because they were in Britain before as well as after the submergence, and were living throughout in those parts of Europe which were not submerged. It can only be done in areas

[1] See *Cave Hunting and Early Man.*

where the submergence is clearly defined. At Salisbury, for instance, the River-drift hunter may have lived either before, during, or after the southern counties became an island. When, however, he hunted the woolly and leptorhine rhinoceros, the mammoth, and the horse in the neighbourhood of Brighton, he looked down upon a broad expanse of sea, in the spring flecked with small icebergs, such as those which dropped their burdens in Bracklesham Bay. At Abbeville, too, he hunted the mammoth, reindeer, and horse down to the mouth of the Somme on the shore of the glacial sea.

The evidence is equally clear that the River-drift hunter followed the chase in Britain after it had emerged from beneath the waters of the glacial sea, from the fact that the river-deposits in which his implements occur either rest upon the glacial clays, or are composed of fragments derived from them, as in the oft-quoted cases of Hoxne and Bedford. Further, it is very probable that he may have wandered close up to the edges of the glaciers then covering the higher hills of Wales and the Pennine chain.

The severity of the climate in winter at this time in Britain is proved, not merely by the presence of the arctic animals, but by the numerous ice-borne blocks in the river gravels dropped in the spring after the break-up of the frosts.

The Range of the River-drift Man on the Continent and in the Mediterranean Area.

The River-drift man is proved, by the implements which he left behind, to have wandered over the whole of France, and to have hunted the same animals in the valleys of the Loire and the Garonne as in the valley of the Thames. In the Iberian peninsula he was a contemporary of the African elephant, the mammoth, and the straight-tusked elephant, and he occupied the neighbourhood both of Madrid and Lisbon. He also ranged over Italy, leaving traces of his presence in the Abruzzo, and in Greece he was a contemporary of the extinct pigmy hippopotamus (*H. Pentlandi*). South of the Mediterranean his implements have been met with in Oran, and near Kolea in Algeria, and in Egypt in several localities. At Luxor they have been discovered by General Pitt-Rivers in the breccia, out of which are hewn the tombs of the kings. In Palestine they have been obtained by the Abbé Richard between Mount Tabor and the Sea of Tiberias, and by Mr. Stopes between Jerusalem and Bethlehem. Throughout this wide area the implements, for the most part of flint or of quartzite, are of the same rude types, and there is no difference to be noted between the *haches* found in the caves of Cresswell in Derbyshire, and those of Thebes, or between those of the valley of the Somme and those of Palestine. Nor is our survey yet ended.

The River-drift Man in India.

The researches of Foote, King, Medlicott, Hacket, and Ball establish the fact that the River-drift hunter ranged over the Indian peninsula from Madras as far north as the valley of the Nerbudda. Here we find him forming part of a fauna in which there are species now living in India, such as the Indian rhinoceros and the arnee, and extinct types of oxen and elephants. There were two extinct hippopotami in the rivers, and living gavials, turtles, and tortoises. It is plain, therefore, that at this time the fauna of India stood in the same relation to the present fauna as the European fauna of the late Pleistocene does to that now living in Europe. In both there was a similar association of extinct and living forms, from both in the lapse of time the genus *Hippopotamus* has disappeared, and in both man forms the central figure.

The River-drift Hunter in North America.

We are led from the region of tropical India to the banks of the Delaware in New Jersey by the recent discoveries of Dr. C. C. Abbott in the neighbourhood of Trenton. After a study of his collections in the Peabody Museum at Cambridge, Mass., I

had the opportunity of examining all the specimens found up to that time, and of visiting the locality in company with Dr. Abbott and Professors Haynes and Lewis. The implements are of the same type as those of the river gravels of Europe, and occur under exactly the same conditions as those of France and Britain. They are found in a plateau of river gravel forming a terrace overlooking the river, and composed of materials washed down from the old terminal moraine which strikes across the State of New Jersey to the westward. The large blocks of stone and the general character of the gravel point out that during the time of its accumulation there were ice-rafts floating down the Delaware in the spring, as in the Thames, the Seine, and the Somme. According to Professor Lewis it was formed during the time when the glacier of the Delaware was retreating ('late glacial'), or at a later period ('post-glacial'). The physical evidence is clear that it belongs to the same age as deposits with similar remains in Britain. The animal remains also point to the same conclusion. A tusk of mastodon is in Dr. Cooke's collection at Brunswick, New Jersey, obtained from the gravel, and Dr. Abbott records the tooth of a reindeer and the bones of a bison from Trenton. Here, too, living and extinct species are found side by side.

Thus in our survey of the group of animals surrounding man when he first appeared in Europe, India, and North America, we see that in all three regions, so widely removed from each other, the animal life was in the same stage of evolution, and 'the old order' was yielding 'place unto the new.' The River-drift man is proved by his surroundings to belong to the Pleistocene age in all three.

The evidence of Palæolithic man in South Africa seems to me unsatisfactory, because as yet the age of the deposits in which the implements are found has not been decided.

General Conclusions.

It remains now for us to sum up the results of this inquiry, in which we have been led very far afield. The identity of the implements of the River-drift hunter proves that he was in the same rude state of civilisation, if it can be called civilisation, in the Old and New Worlds, when the hands of the geological clock pointed to the same hour. It is not a little strange that his mode of life should have been the same in the forests to the north and south of the Mediterranean, in Palestine, in the tropical forests of India, and on the western shores of the Atlantic. The hunter of the reindeer in the valley of the Delaware was to all intents and purposes the same sort of savage as the hunter of the reindeer on the banks of the Wiley or of the Solent. It does not, however, follow that this identity of implements implies that the same race of men were spread over this vast tract. It points rather to a primeval condition of savagery from which mankind has emerged in the long ages which separate it from our own time.

It may further be inferred, from his wide-spread range, that the River-drift man (assuming that mankind sprang from one centre) must have inhabited the earth for a long time, and that his dispersal took place before the glacial submergence and the lowering of the temperature in Northern Europe, Asia, and America. It is not reasonable to suppose that the Straits of Behring would have offered a free passage, either to the River-drift man from Asia to America, or to American animals from America to Europe, or *vice versâ*, while there was a vast barrier of ice or of sea, or of both, in the high northern latitudes.

I therefore feel inclined to view the River-drift hunter as having invaded Europe in pre-glacial times along with the other living species which then appeared. The evidence, as I have already pointed out, is conclusive that he was also glacial and post-glacial.

In all probability the birthplace of man was in a warm if not a tropical region of Asia, in 'a garden of Eden,' and from this the River-drift man found his way into those regions where his implements occur. In India he was a member of a tropical fauna, and his distribution in Europe and along the shores of the Mediterranean prove him to have belonged either to the temperate or the southern fauna in those regions.

It will naturally be asked, to what race can the River-drift man be referred?

The question, in my opinion, cannot be answered in the present stage of the inquiry, because the few fragments of human bones discovered along with the implements are too imperfect to afford any clue. Nor can we measure the interval in terms of years which separates the River-drift man from the present day, either by assuming that the glacial period was due to astronomical causes, and then proceeding to calculate the time necessary for them to produce their result, or by an appeal to the erosion of valleys or the retrocession of waterfalls. The interval must, however, have been very great to allow of the changes in geography and climate, and the distribution of animals which has taken place—the succession of races, and the development of civilisation before history began. Standing before the rock-hewn tombs of the kings at Luxor, we may realise the impossibility of fixing the time when the River-drift hunter lived on the site of ancient Thebes, or of measuring the lapse of time between his days and the splendour of the civilisation of Egypt.

In this inquiry, which is all too long, I fear, for my audience, and all too short, I know, for my subject, I have purposely omitted all reference to the successor of the River-drift man in Europe—the Cave man, who was in a higher stage of the hunter civilisation. In the course of my remarks you will have seen that the story told by the rudely chipped implements found at our very doors in this place, forms a part of the wider story of the first appearance of man, and of his distribution on the earth—a story which is to my mind not unfitting as an introduction to the work of the Anthropological Section at this meeting of the British Association.

FRIDAY, AUGUST 25.

The following Reports and Papers were read:—

1. *Report of the Committee for obtaining Photographs of the Typical Races in the British Isles.*—See Reports, p. 270.

2. *Report of the Committee on the Investigation of Loughton Camp.*—See Reports, p. 274.

3. *Report of the Anthropometric Committee.*—See Reports, p. 278.

4. *The Names Britannia and Hibernia, with their Iberian Relations. By* HYDE CLARKE, *V.P.A.I.*

Continuing his researches of 1871, the author carried them further by showing that the termination Nia signifies land or country, leaving the roots, as RD (RT, LD, LT, DR. DL, TR, TL) and BR (BL, RB, LB). These roots are found in the ancient island names for 'Britannia,' in Brattia, Sardinia, Sardena, Rhodus, Aratus, Maratha, Kreta (Crete), Cytherea, Hydræa, Theræ, Carthea, Andros, Delos, Æthalia (Elba), Telos, Petalia, Mytilene (Lesbos), Thule, 2 Melita; and for 'Hibernia,' Phaura, Pharus, Paros, Ephyræ, Lipara, Imbros, Hippuris, Kupros (Cyprus), Aperopia, Proni, Peparethus, Pylora, Tiparenus, Sapirene, Kephallenia, Capreæ, Karpathos. The emblems on the coins of islands, he showed, included the sun, moon, vase, fish, ship (balsa), being round objects. These emblems also occur on the coins of cities of corresponding name, as Rhodia, Marathus, &c. The roots RD and BR were applied to round objects, but only secondarily to islands, as they are primarily applied to mountains (and in a later stage to rivers as taking their origin in mountains). Tables were given of parallel names of mountains, islands,

and rivers. Thus the names of 'Britannia' and 'Hibernia,' and other allied names, were found to signify 'mountain-land = island.' Taking Britannia and Hibernia together, they were found to be names of pairs of islands. Examples were Britannia and Hibernia; Brattia and Pharus; Hydræa and Tiparenus; Kreta and Kuprus; Thera and Hippuris. Of other sets of pairs are Sardo, or Sardinia, and Corsika; Andros and Keos; Rhodus and Kos; Melita and Aaulos, &c. A similar practice prevails in Japan, where in a pair the larger island is marked by the male prefix and the smaller by the female prefix. Mr. Clarke concluded that our islands were named by the Iberians on a common system of geographical nomenclature, and that Thule must have been an island known to the earliest Iberian navigators, and was most likely Iceland. Our islands must have been named in the early epoch of the foundations of the first empires. This was confirmed by the Celtic names for Hibernia and Caledonia, which transmitted the earlier traditions. He considered it was possible that Albion was another name for Britannia belonging to the same class.

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5. *Evidence as to the Scene of Man's Evolution and the Prospects of proving the same by Palæontological Discovery. By* W. STEWART DUNCAN, *M.A.I.*

The object of this paper was to recall attention to a lately neglected department of anthropology, namely that which concerns itself with the discovery of forms in fossil proving the evolution of man. It was urged that a committee should be appointed to investigate this subject specially, and to report to the Association. In support of his proposition the author advanced a series of arguments in favour of the region of the South of Europe and Asia as the probable scene of man's evolution, and as a likely field of successful exploration. This conclusion was reached as follows:—On the assumption that man was evolved he must have sprung from a small-brained quadrumanous semi-erect creature; in that case he was evolved in common with ape allies in the Old World. In what part then of the Old World? The equal division of the genera of living anthropoid apes between Western tropical Africa and Indo-Malaya, as also the discovery of fossil anthropoid apes in the extreme South of France, indicated that living Simiadæ were derived from Southern Asia and Europe. The fairly equal division between tropical Africa and Malaysia of the lowest types of mankind indicated that they also were derived from the South of Europe and Asia. But palæontological evidence existed to prove that the monkeys and apes of the Old World became dispersed to this very same region in middle and early tertiary times. Driven thither by increasing cold from the north—the premonition of a coming ice age—they would, if not arrested, have steadily gone on to the equator. But geographical barriers arrested their progress for a long period, for the enormous extent of sea-barrier on the northern Mediterranean shore and on the shore of the Arabian sea and its diverging branches prevented all but those in South-eastern Asia from finding their way to the tropics. Those that found their way thither are comparatively unimproved; those that found their way to Northern Africa by happening to lie near the then probable land connections (by Italy and Tunis, and by Gibraltar and Tangier) between Europe and Africa were again arrested by a Sahara sea or desert, and so attained a higher development in the mountainous region of Morocco and Algeria. But those who never knew of such routes, and they must have been the majority, had to remain and contend with cold. and with their natural enemies among the lower animals. The survivors of these apes would become adapted to withstand a colder climate, and so would become fitted to become universally distributed; increased cold would lessen the abundance of fruit-trees, would necessitate the selection of new kinds of food, would abolish the habit of living in trees; the arms would become shorter with less use, the legs would become more fitted by use to support the body, the foot would become more adapted for support and less for prehension; the pelvis and the spine would assume more of the human characters by the muscular exercise necessitated by living in a mountainous region, such as this was and still is. The brain would

enlarge as a mere result of the quickening given to it from the forces which then had to be contended with. Implements wherewith to secure food and weapons to defend life would first be extemporised, then designedly constructed. Caves would be used, and pit-shelters excavated, and all the marks of developing man would be evoked. May not those disputed evidences of human handiwork such as Miocene and Pliocene implements, and cut bones, be the work of pithecoid man? At least during later Miocene and Pliocene times such a struggle of surviving apes would naturally have taken place in this region as a mere result of the climatal and geographical conditions of that period in Southern Europe and Asia.

The remains marking such a struggle ought to be found in part among the deposits which flank the Eocene-capped mountains with which this region abounds. Moreover, these deposits would have been made accessible by having been inclined by the gradual elevation of these mountains known to have taken place in the Miocene and Pliocene epochs. These deposits cannot have been very greatly denuded away, for where glaciation has been greatest deposits of that date are found. They are therefore likely to be found abundantly elsewhere within this region.

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6. *On the Length of the Second Toe of the Human Foot.* *By* J. PARK HARRISON, *M.A.*

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7. *Ebb and Flow in Mental Endowment.* *By* GEORGE HARRIS, *LL.D.*, *F.S.A.*

The theory propounded by the writer of this paper is that there is frequently to be discovered in a succession of persons in the generation of particular families, an ebb and flow both of mental capacity and moral qualities; a person of ordinary endowment having a son of superior power, who has a son of great capacity, by which he becomes distinguished and rises in the world, although his own son turns out to be an individual of capacity below the average.

The writer referred to the question of the supposed transmission of endowments acquired by cultivation, and started the inquiry whether in the cases of transmission of qualities to the offspring, the intellectual or moral condition of the parent at the time of the procreation of the child, is that from which the transmission of such qualities is derived.

The writer also referred to the biographies of distinguished persons, where accounts are given of the qualities of their progenitors and descendants, as affording proof of the correctness of his theory.

The conclusion at which the writer arrived was that there is existent in our constitution certain operations and impulses analogous to, or corresponding with, those of tide and reflux, exhaustion and repletion, action and reaction, wearing out and revivifying, in the material world, ever in process, as regards the origination, development, and growth of our moral and intellectual endowments, as well as in the properties of our physical frames, which possess a never-failing influence in respect to the transmission of these qualities and their manifestation in the offspring, particular endowments going on for generations increasing, until they reach their climax, when they at once decline.

In the animal world he pointed out that an analogous growth and decline of qualities may be observed.

He also remarked that education and training, to some extent, but only very partially, can account for the phenomenon in question.

SATURDAY, AUGUST 26.

The Department did not meet.

MONDAY, AUGUST 28.

The following Papers were read:—

1. *On some Customs of the Aborigines of the River Darling, New South Wales. By* F. BONNEY.

The author had resided as one of the early European settlers in the district on the north side of the River Darling, and had enjoyed unusual opportunities of learning their habits. In this communication he restricted himself to sundry customs connected with the more important epochs of life. He stated that infanticide is frequent, owing to the difficulty of carrying children from place to place. If, however, the child is not killed (and this is decided directly after birth) the parents quickly become much attached to it, and the children generally are very kindly treated. About the age of ten, sundry marks are made in the flesh both of boys and girls. The former, when about the age of sixteen, are initiated into manhood by having one front tooth knocked out, or sometimes by some other ceremonies in place of this. At this time the youth remains apart from the camp, in company with one or two friends, for from ten days to a month, and for the first two days is fed only on blood drawn from his friends' arms. The customs of marriage are described, and their methods of healing the sick. Disease is supposed to be caused by the incantations of an enemy. The method of performing this and of annulling its effect were described, and some account given of the prevalent diseases. The corpse is buried immediately after death, and before entombment is interrogated as to who caused its end. The direction in which it swings when struck is supposed to give an answer, and an attempt is made to punish the supposed aggressor. A small piece of flesh is usually cut from the corpse, which has several peculiar uses. The habits of mourning were also described. The paper was illustrated by numerous photographs taken by the author, and specimens of native industry.

2. *Pre-historic Remains in the Deposits of the Bovey Basin, South Devon. By* W. PENGELLY, *F.R.S.*

3. *The Light thrown by the Exploration of Caves on the Conquest of Britain. By* Professor W. BOYD DAWKINS, *M.A., F.R.S.*

4. *The Jutes of the Isle of Wight. By* J. PARK HARRISON, *M.A.*

5. *On the Physical Characteristics of the Saxon. By* J. PARK HARRISON, *M.A.*

6. *The Lolo Character of Western China. By* HYDE CLARKE, *V.P.A.I.*

The Royal Geographical Society has published a supplementary paper, 'Travels in Western China,' by E. Colborne Baker. This contains plates describing a MS.

from Ssu Chuen, obtained from a hill tribe calling itself Lolo. Mr. Clarke had, at a previous meeting of the British Association, called attention to a MS. brought by Captain Gill, R.E., from another tribe of Western China, called Moso. The Lolo characters Mr. Clarke found to be not the same as the Moso, but having many resemblances and identities. The Moso contains also many ideographs, and is of the same nature as the Khita inscriptions from Hamath, Carchemish, Asia Minor, &c., and also characters to be found in syllabaries and alphabets throughout the world. One of the most remarkable circumstances in Lolo is the many resemblances to the Vy, or Vei syllabary of Western Africa, supposed to be of modern invention, but which Mr. Clarke had explained to the British Association to be of ancient material. Generally speaking the like characters are in different positions in Lolo and Vy. Thus ᘕ and 5; Ǝ and E; = and ‖; ⌶ and H; 3 and ɛ; ÷ and ·|·, and other more peculiar combinations. The Moso has an organisation like the Khita (Hittite), the Lolo more like the Vy, but with combinations like the Khita. The explanation to be assigned is that all the existing syllabaries are derived from an ancient system, which has been differently developed in various regions, and there is this remarkable consequence, that the ancient systems are still in operation in the Lolo, the Moso, and the Vy, at the extremities of the Old World, in China and in Western Africa.

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7. *On the Formula of Alfred R. Wallace in its relations to Characters and Alphabets.* By HYDE CLARKE, *V.P.A.I.*

Mr. Wallace (*Nature*, xxiv. p. 244, 1881) called attention to words for *mouth* in many languages being labials; for *teeth*, dentals; and for *nose*, nasals. This observation Mr. Clarke extended by means of the list he had published of old Chinese round characters which he had supposed to be derived from the eye. Taking the mouth as the pivot, then, ○ (□ in modern Chinese) was the character for mouth, eye, ear, head, face, sun, moon, mother, woman, egg, flower, field or enclosure, doorway, ring, blood, pot, white, four. In Chinese several of these are still labials in M, and so they are in English. Mr. Clarke had shown that in many languages these words are allied in sound, and are labials—characters include ○ ☾. Where, however, the idea of eating, &c. is introduced, a dental may displace a labial in the word for mouth; and so other words are liable to be displaced by other ideas and sounds. The nasal roots Mr. Clarke found to belong to the series he had already demonstrated in Chinese as the + series. As the labials are female, so are the nasals male; and the characters appertaining include + + ⊤ ·|· ÷ N, &c. Mr. Clarke has found that the dental series embraces such ideas as tooth, hill, island, door, drum, arrowhead, with the characters Λ, Δ, ΔΔΔ. The result is that speech-language was founded on the ideas of gesture- or sign-language, and that characters, according to the observations of Colonel Mallery and Mr. Clarke, are applicable not only to speech-language but to gesture-language. Mr. Clarke therefore considers that characters were more ancient than speech, and that speech was propagated in the Old and New World by a race of high culture, most probably white. The consequence is that all languages in the world are found to be connected, and to have many resemblances of sound; but the general connection is psychological, a connection of ideas and not of sounds. In this sense, all language is of common origin, but no one primeval language ever existed. The community of sound depends on the application of labials, nasals, and dentals to associated ideas, but differentiality begins with the selection of the labial, &c. As selection took place of the various ideas, so did the substitution of other sounds take place. On applying the test of the primary characters to ancient characters, syllabaries, and alphabets, it was shown that as a general law those which should be labials were of the labial form, and so of the others. Thus Korean was found strictly to correspond, although apparently artificial, and Vei, supposed to be of modern invention, proved to be ancient in its elements. Mr. Clarke considered that the trine law in grammar may have been developed on the system of 3 sounds, as 3 parts of speech; 3 divisions of each; 3 numbers, 3 cases, 3 degrees, 3 persons, 3 forms of verbs, 3 moods, 3 tenses, 3 positions of adverbs, &c.

8. *The City of the Tarquins.* *By* Miss A. W. Buckland.

In describing a short visit paid two years ago to Corneto, the modern representative of old Tarquinii and to the Necropolis of the ancient city, Miss Buckland points out how few travellers forsake the beaten track to investigate the relics of a people anterior to the Romans and their instructors in most of the arts, as well as their teachers in religious rites and divination. Yet these people have left behind them innumerable works of surpassing interest, showing an affinity with those of Egypt, Assyria, and Greece, yet bearing a distinctive character of their own. The legends of this ancient people make them a colony of Lydians, driven by famine from their own land and settling among the prior inhabitants of Italy, who were probably an admixture of Umbrians and Pelasgians, or as some prefer to call them, Tirrhenians, although this name is also applied to the Etruscans.

This Lydian colony, led by Tarchon, the companion of Æneas, landing probably at Civita Vecchia, founded Tarquinii, so called from Tarchon, of whom the legend further relates, that ploughing on what is now the Necropolis, a boy, named Tages, with grey hair, sprang up under his plough. Tages instructed the Etruscans in religion and the arts of government; and Miss Buckland looks upon this grey-haired boy as a personification of the former inhabitants, from whom the Etruscans adopted much, and points out that the jewellery formerly ascribed to the Etruscans is assigned by Castellani to this former race, whilst the well-known vases are of Greek origin, the manufacture having been introduced from Corinth by Demaratus, the father of Tarquinius Priscus. The earlier Etruscan ware is black and unpainted, but sometimes ornamented with raised figures. The Etruscans were most famous for their works in bronze, which seem to have been exported to all parts of Europe, and they probably obtained the tin necessary for the manufacture from Britain, since articles found in the tombs show a very extensive commerce.

The tombs of Tarquinii differed much from those of the Romans, being subterranean and very elaborately painted; there are facsimiles of some of these paintings in the British Museum, but fresh discoveries are constantly made, as the Necropolis is now being excavated by the Italian Government. Besides the painted tombs the Necropolis of Tarquinii contains many fine tumuli, resembling those in our own land, and Miss Buckland suggests that antiquaries might find much of interest in excavating these, as also the site of the ruined and utterly forsaken city of Tarquinii. where possibly a clue to the Etruscan language, so long sought in vain, might be discovered.

Among the interesting objects from the Necropolis, now collected in a newly formed museum at Corneto, Miss Buckland mentioned several situlæ, which are dressing cases of bronze, elaborately ornamented, containing all the necessaries of a lady's toilet; several beautiful vases and dishes of glass, resembling the Phœnician, two sets of false teeth, fastened together with flattened gold wire, and a large number of mirrors and vases; also sarcophagi and cists, beautifully sculptured in relief and painted. The tomb-paintings show that women in Etruria were treated as equal to men, enjoying the same rights and privileges, descent being traced through the mother, which probably shows that the Etruscans were a non-Aryan race, although their origin is not yet determined. They have disappeared from history, leaving only their sepulchres, works of art, and great engineering works, particularly in drainage and subterranean aqueducts, to the ruin of which Miss Buckland ascribes much of the increased unhealthiness of the Maremma and Campagna.

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9. *The Influence of the Intellectual Faculties in relation to the Direction and Operation of the Material Organs.* *By* George Harris, *LL.D., F.S.A.*

The object of the writer of this paper is to point out the extent to which, and the mode in which, the discipline and cultivation of the material voluntary organs including more especially the senses and the hand, may be affected by the operation

of the mind upon them, so that by the training of the latter the complete and systematic regulation of the former may be accomplished. He observed that in many of our mental operations, where a corporeal organ is resorted to, it occasionally appears difficult to determine whether the mind, or the material organ, is that which is mainly employed.

By the cultivation of the senses it is that the acuteness and the susceptibility of the organ to perceive, not the power of the mind to receive impressions from the sense, are enlarged. It is in fact altogether an animal or material improvement that takes place, and through which we obtain a considerable share of that power with which animals are so extensively endowed, particularly in those sensations, such as feeling and touching, and smelling and tasting, which peculiarly appertain to the animal part of our nature.

Thus also the hand, by cultivation, acquires dexterity, quite independent of the improved skill of the mind to direct it; which in its turn may be, in many cases, also improved both in its actual power and in its ability to receive impulses from the senses. The writer alluded to the various employments of the hand as the organ of the mind, in playing on a musical instrument, in mechanical operations, and in drawing. And he pointed out the necessity, in order to carry out to perfection the maintenance of this communication between the mind and the material organs of each kind, of both the intellectual faculties and the organs to be disciplined to their rule obtaining a thorough and systematic cultivation. The mind itself, he asserted, is never liable to fatigue, although the material organs on which the mind acts suffer from constraint in their operation when impelled so as to incur this, by the influence of the mind. The left hand is unable to act as efficiently as the right as an organ of the mind, simply from the general neglect to discipline it. The discipline and training of each of the organs is best and most efficiently acquired during youth; while the importance of the acquisition it is impossible to over-estimate.

Section E.—GEOGRAPHY.

President of the Section.—Sir Richard Temple, Bart., D.C.L., G.C.S.I., F.R.G.S.

[For Sir Richard Temple's Address, see p. 613.]

THURSDAY, AUGUST 24

The following Papers were read:—

1. *The Arctic Campaign of 1882.—Its Origin, Constitution, and Objects.* *By* Lieutenant G. T. Temple, *R.N.*, *F.R.G.S.*

After referring to the revival of public interest in Polar research which has taken place of late years, Lieutenant Temple gave a slight sketch of the salient features of Arctic discovery during the middle ages, showing how the quaint fancies of the early philosophers gradually gave place to the intensely practical investigations of modern times. He said that the great value and importance of scientific inquiry in the Arctic regions had long since been acknowledged, and that special attention had been paid to it by all the more recent Arctic expeditions. But, while important results in various departments of science had consequently been obtained, they had hitherto been too isolated and scattered to admit of comprehensive generalisation. To remedy this state of things, Lieutenant Weyprecht and Count Wilczec had taken energetic measures to rouse public interest in a scheme of international co-operation, the details of which were finally agreed upon at the Polar Conference held at St. Petersburg in July 1881, amongst them being the establishment of fourteen stations—twelve in the Arctic, and two in the Antarctic regions. Lieutenant Temple then gave some details of the nature, period, and frequency of the observations to be made, and stated that England would co-operate with the Polar Commission by watching the general meteorology of the North Atlantic. Referring to the circular issued last spring by the Meteorological Council, he said it might be confidently expected that shipowners and officers would render cordial assistance in furthering an inquiry in which they were so deeply interested. He thought that, considering the enormous amount of labour which would be required to tabulate and reduce for comparison the mass of material which is almost sure to be forthcoming, it would be admitted that England took a prominent part in the campaign, in thus supplementing the work of the fixed stations, while the patriotism and enterprise displayed by the Meteorological Office reflected credit on the whole nation.

With regard to the purely geographical part of the campaign, Lieutenant Hovgaard's spirited enterprise, of which a detailed account was given, was a good illustration of the fact that, though the area of the unknown region has been greatly reduced during the present century, there is still ample scope for ingenious speculation as to the distribution of land and water about the Pole. Lieutenant Temple then gave some particulars of the American, Dutch, and other exploring expeditions of the year, with an outline of the sad story of the *Jeannette*, and a sketch of the measures taken for the relief of Mr. Leigh Smith. He paid a warm tribute to the devotion and heroism of the officers and men of the *Jeannette*, and said that they could not have won for themselves a more imperishable name, even if they had succeeded in reaching the Pole. In conclusion, he remarked that the Arctic campaign of 1882 marked a fresh point of departure in Polar investigation, which might now be considered as an accepted branch of study, and there could be little doubt that the whole physical economy of the Polar regions would, sooner or later, be brought to light. The one thing necessary to ensure success was continuity of effort.

2. *Notes on a visit to the Chukchi Peninsula in* 1881, *based on letters from Drs. Arthur and Aurel Krause. Communicated by the Bremen Geographical Society.*

The brothers Krause, who were sent by the Bremen Geographical Society for the purpose of making scientific observations in Bering's Strait, landed in Lawrence Bay in August 1881, and visited twelve different localities before the middle of September, from Plover Bay in the south, to Uédle, just within the Arctic circle. This, the largest village met with, is on the northern side of East Cape, with eighty-three huts and some 260 inhabitants. The travellers made considerable collections of plants, obtained many objects of ethnological interest, took dredgings and soundings, and made rapid surveys of various parts as yet imperfectly represented in charts.

The Chukchis were found to be much reduced in numbers by famine, partly caused by their parting with necessary fur clothing for drink, and partly by whales and walruses being driven from their coasts. The division of this tribe into two classes, distinguished by their habits of hunting marine or land animals, is found to be imaginary, as members of the same family are found in both of them, and their languages do not differ. Tattooing is universal among their women, and their clothing in general resembles that of the Eskimo, with whom they retain commercial relations. Here and there along the coast small communities also were found, differing completely in language, and to some extent in features, from the other Chukchis, and indicating a relationship with the Greenland Eskimo.

The region examined was divisible into three well-marked classes:—1, a stony or licheniferous tundra; 2, a wet-moss tundra; 3, slopes and valleys with comparatively luxuriant vegetation, the willows attaining a height of three feet. Of land mammals only Siberian marmot and the whistling hare (*Lagomys hyperboreus*) were met with; but according to the natives, wild reindeer, mountain sheep, foxes, bears, and wolves occasionally make their appearance on the coast.

The travellers returned to San Francisco early in November, and afterwards passed the winter in Alaska, where one of them remains, with the object of examining the basin of the Yukon river.

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3. *The question of an Overland Route to China from India* viâ *Assam, with some remarks on the source of the Irrawaddi River. By* CHARLES H. LEPPER, *F.R.G.S., M.R.A.S.*

The author traced a short history of the little already done to solve the important problem indicated by the title, and showed that there is steam-transit all the way from Europe to our extreme north-eastern frontier outpost nearest to China, viz. Makum, and that there is no physical objection against continuing the railway now in progress of construction to Makum from that outpost all the way to the banks of the Irrawaddi river. He pointed out that the inhabitants of the country through which this extension of the railway would have to pass are Singphos, who are very friendly to the English, and are quite independent of the Burmese, and also of the Chinese. These Singphos have further expressed a wish that a road should be made through their country, as they are alive to the advantages they would reap from it. Mr. Lepper then explained that Chinese traders already visit and settle amongst these Singphos, on this independent, or as he calls it 'neutral ground,' and that were a road or railway continued from Makum to the Irrawaddi, a distance of only about 120 miles, there can be little doubt the adventurous Chinese traders who now traffic on the Irrawaddi would be induced to come to us for British merchandise. Thus the whole of Western China would be thrown open to British commerce, without the necessity of any treaty with China, and without any European having to cross the Chinese frontier. Further, the Thibetans, who already trade in this western part of China, would avail themselves of these Chinese traders as intermediaries between themselves and us, and in this way Eastern

Thibet would also be opened to British commerce, and English goods would take the place of Russian goods, which latter now almost exclusively represent European markets in Western China and Eastern Thibet. With steam-transit all the way from Europe to the banks of the Irrawaddi, at the latitude mentioned there could be little doubt that the question of the best route from India to China overland would be solved, as the road would nowhere enter or be subject to the King of Burma's dominions, and thus our goods would be landed without dues or 'squeezes' at the very frontier of China, practically speaking.

Mr. Lepper pointed out that notwithstanding the new era which is sure to open for this frontier once the railway to Makum is opened—next year—nothing is being done to prepare for the new order of things, and that there is not a single European who can speak the Singpho language, or who knows the prejudices, manners, and customs of the Singphos, although Makum itself is situated among Singpho villages, which are scattered about and within our frontier in this direction. He then explained the advantages which would be derived on the opening of this route by British merchants, owners of tea properties in Assam, the Public Works Department of Assam, and last, but not least, by Bengal in its times of famine. Mr. Lepper then called attention to certain data he had collected, which went to show that the Irrawaddi could not take its rise much further north than latitude 28° 30′.

4. *Notes on the oldest Records of the Sea-Route to China from Western Asia. By* Colonel H. Yule, *C.B., R.E.*—See Reports, p. 347.

FRIDAY, AUGUST 25.

The President delivered the following Address:—

The Central Plateau of Asia.

The subject chosen for this address is the Plateau of mid-Asia. This area, which is one of the most wonderful on the surface of the earth, contains nearly 3,000,000 English square miles, and is equal to three-fourths of Europe. Its limits, its exterior configuration, its central and commanding situation in the Asiatic continent, will be clearly perceived from the large diagram of Asia which is exhibited here.[1] As compared with some of the more favoured regions, it is singularly destitute of natural advantages. Though it has several deep depressions of surface, yet its general elevation is very considerable, and some of its large districts are the most elevated in the globe. It is walled in from the outer world and excluded from the benign influences of the sea by mountain chains. Its climate then is very severe on the whole, more distinguished for cold than for heat, but often displaying extremes of temperature high as well as low. It offers, from the character of its contour, extraordinary obstacles to communication by land or water. Though seldom inaccessible to courageous explorers, it is generally hard of access, and in several respects very inhospitable. In the progress of civilisation it is, with reference to its historic past, excessively backward. Its capacities for the production of wealth have been but little developed. Its population is scanty, scattered, and for the most part uncultured. Its agriculture comprises only a few areas widely segregated from each other, and many of its largest districts are amazingly desolate.

Nevertheless this plateau has eminent claims on the attention of geographers, for several reasons which may be summarised thus:—

1. A mountain system which dominates the greater part of Asia, and includes stupendous ranges with the loftiest peaks yet discovered in the world.

[1] See an able disquisition on this subject in 'The Himalaya System,' by Trelawny Saunders, Geographer of the India Office, to whom I am much indebted for suggestions regarding the plateau.

that the outer border of our plateau north of the Pamir is formed by the terminal spurs of the Thian Shan. It is to be remembered also that the Indian Caucasus—which does not concern our plateau directly enough to fall within this address—probably joins the Pamir. In general terms, the convergence of mountain ranges on the Pamir renders it geographically the most important position in Asia. The uninstructed Asiatics have evinced a hazy admiration of its grandeur by calling it 'the roof of the world.' The comparatively instructed Europeans have revered it as the source of the classic Oxus and as fraught with political considerations. Unless further discoveries shall alter existing information, we may expect that completely informed geographers will consider that this Pamir is the mother of mountains, that other ranges are to it as the branches are to the root, and that here if anywhere is the true boss of the Asiatic shield.

In the second place, the vast surface of our plateau, though almost uninterruptedly environed by its rocky walls, presents an extraordinary series of elevations and depressions. In the heart of the plateau there is the depression known to geographers as the Western Gobi, sometimes called the Tarim basin. Within this there is the Lob Lake or Lob Nor, truly an inland sea into which the waters of several rivers ultimately flow, finding no vent towards the ocean. The total length of the Tarim river, with its affluents debouching into Lob Nor, cannot be less than 800 miles. This curious and interesting lake is not more than 2,000 feet above sea-level, and forms almost the lowest dip in our plateau. It is like the bottom of a vast platter, or the centre in the hollow of a mighty hand. Around this depression there are on all sides uplands of various heights like gradations in the Asiatic terrace terminating in the intermediate ranges, or in the outer circumvallation of mountains already described. On the east of it there is the tract called Eastern Gobi, chiefly desert, and Mongolia, averaging 4,000 feet above sea-level: on the north the Altai uplands, exceeding 5,000 feet. On the west the Pamir rises abruptly, exceeding 13,000 feet; on the south Tibet, with equal abruptness, having an average altitude of 15,000 feet above sea-level, thus being the loftiest expanse in the world; and on the south-east the tract around the Kuku Nor Lake, 10,000 feet.

Further, there is a detached depression known as the Zungarian strait, extending to the northern confine of our plateau between the Thian Shan and the Altai ranges. This strait, hardly exceeding 2,000 feet above sea-level, is as low as, perhaps even lower than, any part of our plateau, and is very near breaking its continuity, which may be considered as being just saved by the comparatively humble altitude above mentioned. The depression is geographically important as forming the only broad pass between our plateau and the world without. It runs from Mongolia, the most important tract within our plateau, to Siberia outside. Great value was, in early times, attached by the Chinese to it, as being the only natural highway on a large scale between Northern and Central Asia.

The existence of this and the other depressions above described has led to interesting speculations among geologists as to there having been, in primeval times, within our plateau, at least one inland sea as large as the Mediterranean of Europe.

Be that as it may, there is no doubt that a process of desiccation has been going on within our plateau during historic ages, whereby the climate is considerably affected, and many signs or evidences show that this process is still in operation.

On most of its sides our plateau is extraordinarily inaccessible, the passes being steep in the extreme, and on the south ending in ridges 18,000 to 20,000 feet above sea-level. Towards Siberia the Altai passes are easier. and on the north-east between Mongolia and China there are several passes that have witnessed the historic outpourings of the Mongol hordes, and which are ominously remembered by the Chinese as the openings through which their invaders rushed like the great river in flood, or the landslip from the mountain side, or the avalanche sweeping along the boulders and *débris* to the destruction of the valleys beneath.

The great desert of Eastern Gobi occupies the eastern portion of our plateau. With its accumulating forces of sand and powdered earth it has a tendency to encroach, and is regarded by man with a vague awe. Its present extent is enormous, being not less than half a million of square miles. Nor does it exist alone within our plateau, for between the Tarim basin and the Kuen-lun spurs there

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is a lesser desert called Takla-makan with 100,000 square miles of area. It may probably be found that these two deserts join or are otherwise connected.

In the third place we have noted that while the prevailing characteristics of our plateau are wildness, ruggedness, or desolation, yet within it are the sources of several great rivers which sustain the most teeming peoples on the face of the earth. The monarch as it were of all these noble waters is the Yang-tse-Kiang. Though its head streams have been but imperfectly explored, yet its true source is known to be in the Kuen-lun mountains already mentioned. After quitting our plateau and passing out of its prison-house in the mountains through natural gates of the utmost magnificence, it permeates the most thickly-peopled provinces of China—provinces inhabited by about 120 millions of souls. It sustains the life of this enormous population by supplying the necessary moisture and by affording the means of irrigation and of water-traffic. No river has ever in ancient or modern times played so important a part in the increase of the human race as the Yang-tse-Kiang. Its supply of water is immense and unfailing, and this most essential characteristic is caused by its connection with the snow-clad and ice-bound regions of our plateau, within which it has a course of 700 miles before entering China proper. Amidst the same Kuen-lun range, the Hoang-ho rises, from unexplored springs, which the Chinese figure to themselves as 'the starry sea.' After bursting through several ranges, making wondrous bends from its main direction near the base of our plateau, and changing its course more than once to the confusion of comparative geography, it traverses Northern China and confers agricultural prosperity on some 70,000,000 of souls. It also has a course of some 400 miles within our plateau, in consequence of which its water-supply is perennially snow-fed. Again, the Irrawaddi and the Mekhong, the former watering Burma and the latter watering Cambodia, rise in the offshoots of the Kuen-lun. That region, then, in respect of the parentage of important rivers, stands in the first rank. This beneficent circumstance arises from the direction of subsidiary ranges which admit to this part of our plateau some of the moisture-laden breezes from the Pacific Ocean.

Similarly the two Indian rivers, the Brahmaputra, and the Indus with its affluent the Sutlej, have their origin at a great distance within our plateau, and their water-supply is indefinitely augmented in consequence. Notwithstanding the vast volume of their waters, these rivers play an economic part which, though great, is much less than that of the main Chinese rivers. The Brahmaputra, above its lower course as the Megna, cannot be said to sustain more than 15,000,000 of people; and the Indus, together with the Sutlej, may support 12,000,000. The Ganges and Jumna, issuing from masses of snow on the southern scarp of our plateau, sustain before their junction at Allahabad a population of 30,000,000 —quite irrespective of the deltaic population of the lower Ganges, for whom moisture is supplied from other sources. Of these Indian rivers the waters, perpetually snow-fed, are largely drawn away for canals of irrigation on a grand scale. Taken all in all, despite defects, the Ganges Canal is the most imposing example of hydraulic engineering that has yet been seen. From the glaciers of the Pamir and the western terminus of the Thian Shan there spring the head-streams of the Oxus, the Jaxartes, and their branches, ending in the inland sea of Aral. To these, in Persian phrase, the epithet of 'gold-scatterer' or 'wealth dispenser' is felicitously applied by the natives.

Of the rivers rising in the northern section of our plateau, the Amur has possibilities of which the future may see the development. But the great rivers of Siberia, such as the Obe, the Yenisei, and the Lena, though flowing through rich soils and affording marvellous facilities for several systems of inland navigation to be connected with each other, yet have their long estuaries in the permanently frost-bound lands of the Tundra, and their mouths in the Arctic waters frozen during most months of the year. Therefore they can never, in economic importance, vie with the rivers above mentioned, which flow into the Pacific and Indian Oceans.

In the fourth place, the lacustrine system, though not comparable to that of North America or of Central Africa, and not approaching in beauty or interest that of Southern Europe, is yet very considerable. It is not, however, the only one in Asia, and from it must be excluded the three great Siberian lakes of Issykkul, of

Baikal, and of Balkash, which, though connected with our plateau, are beyond its actual limits. Exclusive of these, however, the lakes, great and small, within our plateau, are extraordinarily numerous. Not less than a hundred of them may be counted on the maps of this region. Of these lakes, however, some are insignificant, being little more than saline swamps. Others, again, as the Pangong, though romantically beautiful—reposing at an altitude equal to that of the highest European mountains, and reflecting the perennial snow of surrounding peaks—do not illustrate specially any geographical problem or produce any economic result. But some may be selected as having a scientific interest irrespective of beauty or of strangeness.

The Lake Victoria, discovered by Wood in 1838, rests in the heart of the Pamir, already mentioned, at an elevation of 15,000 feet above sea-level. It is frozen over during the greater part of the year, and lies with a glistening and polished surface in the midst of a snow-whitened waste. In that state it powerfully affects the imagination of the spectator who reaches it as the final goal, after a protracted and toilsome ascent from the barren or deserted plains of Ariana. It is the source of the Oxus, and is near the point of contact between the British and the Russian political systems in Asia.

In the sharpest contrast to the highly-placed Pamir lake is the lowly Lake Lob, already mentioned. Shallow water, sedgy morass, dreary sands, parched forests—the monotony of desolation—are reported to be its characteristics. It apparently consists of the dregs of an inland sea that is mostly dried up, and is, as it were, kept alive only by the Tarim river, which has its sources in the everlasting snows of the Pamir. Despite the proximity of saline tracts, the lake has fresh water. Near it is a great desert, of which the soil, though now arid and friable, owing to the gradual desiccation, was once more or less productive, and where a population has probably become extinct or has disappeared by migration.

The Pamir then is a water-parting for two inland seas, one the Aral, beyond our plateau, the other Lob Nor within it—both saved from speedy desiccation only by the influx of rivers from the snow-line.

Again in contrast is the Kuku Nor, a sheet of water 10,000 feet above sea-level, in the eastern section of the Kuen-lun mountains, near the source of the Hoang-ho. Its waters, profound and saline, have a dark azure hue, which is compared by the natives to that of the exquisite silks in China. It is in the Tangut region, mentioned by Marco Polo in his Itinerary. In respect to the lakes in this region, and especially the morasses of Tsaidam, there are geological speculations as to another Asiatic Mediterranean (besides that already mentioned), long since dried up, whereof there are a few widely-scattered remnants, among which the Kuku Nor is one.

Lastly, a word of passing notice may be devoted to two among the Tibetan lakes, that of Tengri, near Lhassa, on the shore of which stands a venerated Buddhist convent, and the Bul-tso, from which have been obtained quantities of the best borax.

In the fifth place, the north-eastern part of our plateau was during remote ages, beyond the ken of history, the home of hardy and aggressive Tartars, or, as they may be more properly called, Mongols. These Tartar races, dwelling among the uplands in the lee of the mountains, used for many centuries to emerge and harry the fertile Chinese plains lying between the mountains and the Pacific Ocean. It was to ward off these incursions that the Great Wall was constructed, winding like a vast serpent of stone along the ridges of mountains for 2,000 miles from the Pacific coast to the Siberian confines. The cost and labour expended on this amazing work attest the dread with which the Tartar highlanders had inspired the Chinese lowlanders. Some centuries after the building of the Wall, the most warlike among the Tartar tribes, in the council of their national assembly, acclaimed Temujin as their king, in the year 1206 A.D. He took a title which is translated by Europeans as Chinghiz Khan, a title which for two centuries or more was the best known name in the whole world. At the head of his Tartar adherents, he first subdued the other kindred tribes of our plateau. Then he organised and disciplined the whole Tartar manhood into an army of horsemen. This is the most wonderful instance of military mobilisation known to history ancient or modern. Its results too were equally ap-

palling. In medieval times the marches of the Arabs and the Saracens, in modern times the expeditions of Napoleon, have dazzled Asia or Europe. These were hardly, however, equal to the distant conquests of Alexander the Great in ancient times. But even the wars of Alexander were perhaps surpassed by the ravages of Chinghiz Khan and the Tartars of our plateau. The countries of China, India, Afghanistan, Bactria, Persia, the Aral-Caspian basin, Siberia, Asia Minor, Russia, were overrun within a hundred years by Chinghiz Khan, his lieutenants, and his immediate descendants. Thus, through the hordes of our plateau there was established a dominion stretching from Cape Comorin, near the equator, to the Arctic Ocean, and from the Pacific shores to the banks of the Vistula in Poland. The latest historian of the Mongols considers that nothing but the unexpected death of the Tartar sovereign, and the political combinations arising in consequence within this very plateau of ours, prevented the Tartar invasion from spreading even to Western Europe. Though it is often held that these terrific events have been overruled by Providence for the progress of mankind, still at the time they caused what Gibbon truly calls a shipwreck of nations. Notwithstanding this, the Tartars won, in a certain sense, an unparalleled success, which is attributable to the geographical circumstances of our plateau.

The influence of the precipices, the forests, the prairies, the wild sports, in forming the national character is so obvious that it need not be specified. We readily understand how the sturdy mountaineer, the daring hunter, the practised archer, becomes the able soldier. In Mongolia, however, the local speciality was this, that the practically boundless extent of the pasturage and the nutritious richness of its quality, induced the people to maintain countless horses, cows, buffaloes, sheep, goats, and camels, neglecting the tillage of the soil, never building houses, but living in tents made of warm felt, accumulating a rude wealth, still roving and roaming about at some seasons incessantly from one encampment or one grazing-ground to another, dragging with them their families and their effects by means of the pack animals and the roomy waggons drawn by many oxen yoked abreast. Thus was a truly nomadic existence practised on the largest scale ever known. Mongol armies, better drilled, armed, accoutred, and equipped than any forces then known in the civilised world, would emerge from our plateau into the inhabited plains around, and would observe houses and towns for the first time. It is even alleged that some of them had never seen cultivated crops before.

In this state of existence the temptations to depredation of all sorts were excessive, and the danger from the climate, the savagery of nature, and the wild beasts, was always imminent. Consequently the Mongols were obliged to hold themselves together by the cohesion of families, clans, and tribes. Thus by the force of circumstances a social organisation was established which proved the foundation of a military discipline suitable to the genius of the people, almost self-acting, and unfailing even in the remotest expeditions. The horses, too, upon which the Mongol warriors mainly depended, naturally fell into the training; being always turned out to graze in herds, they habitually kept together, and the field manœuvres fixed habits which had been already acquired. It used to be remarked that a line of Mongol cavalry was like a rope or a chain, perfectly flexible but never parted.

The Mongolian food included little of cereals or vegetables, but consisted mainly of cheese and meat. For stimulating drink there was the fermented mare's milk. The name 'koumis' or 'prepared milk,' apparently much esteemed medically nowa-days, is a Mongolian word. Manifestly, men thus nurtured could live in the saddle day and night, carrying with them their sustenance in the smallest compass, and scarcely halting to eat or drink. Thus the hardihood evinced on protracted marches, which would otherwise be incredible, can be accounted for.

It is probable that this diet while sustaining vivacity produced also a violence of disposition. Certainly, ruthlessness, cruelty, indifference to suffering characterised the Mongols and marred the effect of their grand qualities. Massacres, holocausts, conflagrations marked their warlike operations. Even famines and epidemics have hardly done more for depopulation than the Mongol conquests. A Mongolian chief would say that the keenest enjoyment in life was to stamp upon a beaten enemy, to seize his family, and despoil his encampment.

It is not the purpose of this address to describe the policy of the Mongols or the institutions which they founded in conquered countries. A few salient points only have been indicated in reference to the geography of our plateau. It is here, near what is now known as the upper region of the Amur, that the Onon, the Orkhon, and the Kerulen, classic streams in Mongol story, take their source. Here is the site of Kara Koron, the emperor's head-quarter encampment. Here the Kurultai assemblies were held to decide the fate of nationalities. Here were the camps, the Urts, and Urdus, rude names at first unpronounceable in the civilised world, but soon to become terribly familiar. Here were the hordes mustered under their banners, each standard having its distinctive colour, the supreme ensign being, however, the yak's tail raised aloft. Hither, also, the corpse of Chinghiz Khan was borne in a cumbrous catafalque, dragged through the deep loam by oxen yoked twenty abreast, while his henchmen chanted a dirge which was a pathetic effusion from the heart of a valiant nation, and was full of poetic images drawn from the Mongolian surroundings.

In the sixth place, though our plateau has possessed, and still possesses, some patches of fine cultivation, such as those in the Upper Tarim basin, near Yarkand and Kashgar, and some near Lhassa in Tibet, still it has comparatively but little of agriculture, of trade, or of industry. Nevertheless it has many natural resources of value and interest, while its pastoral resources have proved astonishing. Its breed of horses, though by no means the finest, has yet been quite the largest ever known. These horses have never displayed the beauty of the Arabian or the size of the Turkoman breed. They are middle-sized, and do not attain the speed of thoroughbreds. But in nimbleness amidst rugged ground, in endurance over lengthened distances, and in preserving their condition with scanty nourishment, they are unrivalled. Their numbers too may well exercise the imagination of modern breeders. For many years the Tartar emperors maintained in the field at least 500,000 cavalry, for which the horses were drawn chiefly from our plateau. This enormous cavalry force was engaged in fighting over an area of many thousand miles in length and breadth, during which operations much desperate resistance was encountered. It was occupied in steep ascents and descents, in traversing deserts, in crossing frozen lakes, in swimming rapid rivers. How vastly numerous then must have been the casualties among the horses, and how immense the breeding studs. The pasturage too was so potent in nutritive qualities that ordinarily there was risk of animals suffering from repletion, and emaciated creatures rapidly gained flesh and strength.

In other respects too the fauna is noteworthy—the sheep and goats, with wool or down of the softest texture—the buffalo herds and the yaks inured to the sharpest cold—the gazelles careering in thousands—the untameable camel of the desert having a speed and agility unknown in other species—the wild asses and the white wolves—the waterfowl at times like clouds darkening the air.

The flora too, though less abundant, has its specialities—the pointed grasses sharp enough to pierce leather, the gigantic rhubarb, the magnificent holly, the branching juniper.

The mineral resources of the Kuen-lun are certainly enormous; nobody yet knows how great they may prove. Indeed our plateau is remarkable for its antimony, its sulphur, its saltpetre, its borax, its gold-washings, its turquoise, and its classic jadestone.

In the seventh place, the field offered by our plateau for scientific research will be apparent from even a cursory consideration of the stage to which our knowledge has reached. From the second of the two diagrams, which shows in deep pink those portions of Asia that have been professionally surveyed, in light pink those that have been roughly surveyed, in lighter pink those that have been explored only, and in white those that are unexplored—it will be seen that almost the whole of our plateau is unsurveyed, and that while much of it has been explored more or less, some portions yet await exploration. For some time, however, it has been the sphere chosen by many among the most skilful, enduring, and intrepid travellers of Europe. The journeys of the Russian Prejevalsky in the Tarim basin and Mongolia, of Potanin and Rafailoff in the same region, of Malussovski near

Kobdo, of the French missionaries Gabet and Huc in Mongolia, of Father Desgodins in Tibet, of the German Schlagintweit in Turkestan, of the Englishmen Forsyth, Trotter, Johnson, Shaw, Hayward in the Tarim basin, of Wood in the Pamir, of Ney Elias in Mongolia, of Dilke and Delmar Morgan in Kulja, of Bogle and Manning in Tibet, while teaching us much, have yet left our minds dazed with a sense of what remains to be learnt. Even the trigonometrical determination of the Himalayan summits by the English Surveyors-General, namely, Everest, Waugh, and Walker, the researches of Basevi, Stolicska, Godwin-Austen, Thomson, Biddulph, in the same quarter, and the Siberian surveys by the Russians among the Altai and Tian Shan mountains, have brought us only to the verge of half-discovered or undiscovered countries. The greatest unexplored region in all Asia, namely the Kuen-lun range, lies in the very heart of our plateau. It is remarkable too that if the principal geographical problems awaiting solution in Asia be specified, such as the true and ultimate sources of the Hoang-ho, the Irrawaddi, the Salwin, the Mekhong, the relation of the San-po with the Brahmaputra, the connecting links between the Kuen-lun and the Chinese mountain-chains,—they will be found to concern our plateau.

At a few points only has our plateau been penetrated by geological surveys, namely, in some parts of the Altai and at the western end of the Thian Shan; and these surveys are Russian. In the Himalayas, the Karakuram, and the Western Kuen-lun, the geologists of the Indian Government have begun their researches. But the formations, the strata, the upheavals, the denudations, the fluvial action, awaiting scientific examination, are indescribably great. A notion of some of the questions inviting inquiry from the geologist and palæontologist may be gathered from what has been already said under previous headings in respect to the general desiccation and the subsidence or evaporation of the primeval waters.

To the naturalist few regions present more surprising opportunities for the observation of the coming, the resting, the departing of migratory birds.

To meteorologists many of the natural phenomena must prove highly interesting—the causation of the wondrous dryness, the effects produced on animal comfort by the rarefaction of the air, the mummified bodies dried up without undergoing putrefaction, the clouds of salt-particles driven along by furious gusts and filling the atmosphere, the fires in the parched vegetation of the desert, the spontaneous ignition of coal-beds, the caves emitting sulphurous gases, the rocky girdle of syenite bounding the Gobi desert, the gradual contraction of the glaciers, the ordinarily rainless zones sometimes invaded by rain-storms with a downpour like that of the tropics.

In the eighth place, our plateau is now under one imperial jurisdiction, and offers many problems for social inquirers. It belongs entirely to the Chinese empire with the exception of one small tract where the Russian authorities have crossed the mountain border. The geographical features for the most part favour national defence and territorial consolidation. The old Chinese Wall is still suitable to the political geography of to-day. In the Zungarian strait, however, in the Ili valley near Kulja, perhaps, also, in the line of the Black Irtish, near Zaisan, the Chinese empire, in its contact with Russia, has weak points strategically, or chinks in its armour. Though the plateau was originally under the Chinese suzerainty, it became, under the Mongolian emperor Chinghiz Khan and his successors, the mistress of China, as indeed of all Asia and of Eastern Europe. As the Mongol power, however, shrunk and withered, the Chinese re-asserted themselves. At length, under a dynasty from Manchuria outside our plateau, the Chinese became lords over the regions within its limits. The Zungarian tribe of Eleuths rose, and after severe military operations were suppressed. The Muhammadan inhabitants of the Tarim basin rebelled against the Chinese Government, and for a while maintained an independent principality for Islam. It was during this time that the British sovereign sent an envoy to Yarkand to conclude a commercial treaty, in 1873. Subsequently the Chinese broke down this rising independence, and the whole region of the Tarim receives its orders from the emperor at Pekin.

The decline and fall of the Mongol empire, the disruption of that wide-spread

dominion, like the breaking up of the ice on its own frozen rivers, are historical themes beyond the scope of this address. But the changes which have gradually come over the national character of Mongolians are cognate to the studies of geographers. As already seen, the annals of the Mongols reveal one of the many examples of the theory of causation, explaining how geographical surroundings mould or affect the human character. There remain the mountains, the sea of undulating uplands, which are still among the few important regions not essentially modified by human action. The pine forests, though hardly intact, have not been extensively cleared. There is the dread desert—where to the ears of superstitious Mongols the roll of the mustering drums and the shouts of victorious battle are audible—which has engulfed in sandy waves additional tracts once productive. The pastoral resources, the nomadic diet and exercises, the social arrangements, are in kind the same as of yore, though perhaps modified in extent or degree. The short-lived heat may perhaps be gaining strength as the ages advance; but the winters must be nearly as long and hard as ever. Thus the same physical and climatic conditions which once caused the Mongolian nation to become one of the mightiest engines ever directed by man are still surrounding the politically degenerate Mongols of to-day, who are best represented by the tribe of Khalkas. Once audaciously ambitious, the Mongols are now sluggish and narrow-minded; once passionately fond of an independence as free as their mountain air, they are now submissive to the domination of races formerly despised by them as inferior; once proud of a tribal organisation and a voluntary discipline which wrought world-renowned wonders, they are now split up into factions like a faggot of sticks that has been unbound. A man who, though the feeblest of pedestrians, grips with his bowed legs the saddle of the most restive horse as with a vice, is all that remains of the historic Mongol. It is for the social inquirer to determine what have been the circumstances counteracting the climatic and local causes which made this nation potential in moulding medieval history.

Here too may be observed the tendencies of Paganism, Buddhism, and Muhammadanism respectively. Of all regions our plateau offers the best means of studying Buddhism, which still counts more adherents than any other faith. Though the mid-Ganges Valley was the birthplace of this widespread religion, and was for ages regarded by pious Buddhists as their holy land—yet during recent centuries the active centre of the faith has been in Tibet. Of the four incarnations of Buddha now held to exist, three are within our plateau, namely, two in Tibet near Lhassa and at Teshu Lumbo, and one in Mongolia at Urga, near the spot where mounds attest the burial of heaps of slain after one of Chinghiz Khan's earliest battles. In Tibet may be seen to the best advantage those religious ceremonies, the sight of which has always attracted the observation of Roman Catholic missionaries.

In conclusion, this brief summary of our geographical knowledge regarding the plateau of mid-Asia is provisional only. For it avowedly deals with regions mostly unsurveyed and seldom even explored completely. Further exploration or discovery therefore may reverse some of our specific conclusions, or may modify the current of our topographical ideas. It is probable indeed that there will be such changes, inasmuch as almost every investigation within this vast area has revealed something unimagined before, or has caused disbelief of something previously believed. This address, then, is limited to a *résumé* of things imperfectly known, with a view of bringing into strong relief two matters which are unquestionable, namely, the importance of our plateau and the grand field it offers for research. If the public consideration of these matters shall induce inquirers to direct their enterprise towards this grand region, we may hope that by degrees the errors in our facts may be removed, the misdirection of our conclusions remedied, the vagueness of our notions made definite. At present the physical obstacles in the path of such inquiries are so grave as to be almost deterring. But they do not finally deter those who after forethought decide to brave peril, distress, sickness, suffering, in order to enlarge the bounds of knowledge. Each inquirer, however, has the consolation of reflecting that he makes the rough ways smoother for those who shall come after him. Every journey that is accomplished must facilitate successive

discovery in the same line of country. Probably as fast as one line is made good geographically fresh lines may present themselves, and new vistas will be opened to the astonished gaze of geographers. At length, with all the constancy and courage which arduous travel never fails to inspire, the inquirers of the future will doubtless explore this plateau till it becomes as well known as the Alpine regions of Europe.

The following Papers were read:—

1. *Some points of Physical Geography observed during a recent tour round South America. By* JOHN BALL, *M.A., F.R.S.*

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2. *On the Geographical Evolution of the Tanganyika Basin. By* JOSEPH THOMSON, *F.R.G.S.*

The keynote of this paper is struck by a reference to a recent lecture of Dr. Archibald Geikie, to the Royal Geographical Society, in which he points out that the days are now over in which the scientific geographer is content with the simple description of the superficial aspects of the various regions of the globe. He must also know how they came to be, and what they have been in the past. This line of inquiry is applied by Mr. Thomson to the lake regions of Central Africa, but more particularly to the Tanganyika Basin. In the first place he presented a bird's-eye view of the lake regions from the Indian to the Atlantic Ocean, bringing into relief only the most prominent features of the geography, but describing more in detail the aspect of the Tanganyika Basin, round which the chief interest centres. From a description of these purely superficial matters he proceeded to describe what these have been in the remote past, and the manner in which they have been evolved, being of course compelled to call in the assistance of the sister science geology.

The conclusions he arrived at as to the primary origin of the region were, from purely hypothetical considerations, based on the theory of a shrinking nucleus, and the necessary effects on the earth's crust arising therefrom. At a later stage, however, he was able to appeal to the rocks themselves as to the aboriginal conditions of the African continent south of the Equator. These, according to Mr. Thomson, prove the existence of an immense central sea cut off from the ocean by the elevation of the continent, and which was almost conterminous with the present drainage area of the Congo. An elevated ridge was upheaved along the eastern boundary of this sea, the origin of the trough of Tanganyika, by the collapse of the centre of this ridge and the central sea, subsequently drained away to the west, leaving Tanganyika isolated. Mr. Thomson then proceeded to describe how its secondary characters arose, and its scenery was moulded, by the action of sub-aërial denudation on rocks of different powers of resisting the decomposing and eroding agents, and explained the curious marine-like type of its shells, the origin of its outlet, the Lukuga, the freshening of the water of the lake, and finally the curious intermittency of the outflow.

The various stages in the evolution of the Tanganyika Basin were summarised as follows:—

The first appearance of the future continent, he had been led to believe from various theoretical considerations, was the appearance of a fold of the earth's crust bounded by two lines of weakness converging towards the south, which fold gradually rose till it appeared above the ocean, first along these two lines of weakness, in the form of a series of islands, which finally joined, enclosing in their centre a large part of the ocean. This enclosed water area formed a great central sea, and the enclosing land along the lines of weakness is now indicated by the east and west coast ranges.

In the second stage the continent of Africa south of 5° N. latitude presented the outline of the continent of to-day.

The third stage showed the central plateau with the great central sea very much diminished in size and almost coinciding with the present Congo Basin. There was as yet no evidence of the existence of Tanganyika.

After an enormous period of undisturbed deposition of sand in the sea, the fourth stage was ushered in by a period of great continental convulsions. On the line of the future Tanganyika a huge boss of rock was intruded into the throbbing crust, and the surrounding region elevated to a considerable extent, followed by the subsequent collapse of the body of the elevated area originating the great abyss of Tanganyika.

The fifth great stage was marked by the formation of a channel through the western coast mountain, causing the draining of the great central sea, which immediately became the inner drainage area of the Congo.

The sixth stage then saw Tanganyika isolated as a lake by itself, from which time dates the moulding of its present scenery, the formation of an outlet, the freshening of its waters, and the lowering of its level, and finally the intermittency of the lake's outflow was explained by the probable fact that the rainfall and evaporation nearly balance each other in ordinary seasons.

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3. *On the Royal Geographical Society's Map of Eastern Equatorial Africa. By* E. G. RAVENSTEIN, *F.R.G.S.*

The map, the construction of which had been intrusted to Mr. Ravenstein by the Council of the Royal Geographical Society, was intended to embody, in a tangible manner, all the information that had been collected up to the time of publication. Large as had been the number of African explorers, much yet remained to be done before our knowledge, even of the more accessible parts of Africa, could be looked upon as satisfactory. Apart from the line of coast, where the minute surveys of Captain Wharton and others afforded an excellent base, there were but a few isolated localities which had been determined in a trustworthy manner by astronomical observations. On the Upper Zambezi, Livingstone, Mohr, and Serpa Pinto differed in their results to a very serious extent. Between Zanzibar and Tanganyika the only point satisfactorily determined was the capital of Unyanyembe (which Speke observed), whilst the delineation of the lake depended upon Captain Cambier's determination of Karema. Von der Decken's expedition had supplied trustworthy information as regarded the position of Kilimanjaro and other points nearer the coast. In Southern Abyssinia, M. d'Abbadie's network of triangles, supplemented as it had been recently by Cecchi and Chiarini, afforded an excellent basis for mapping a wide stretch of country. The exact determination of the course of the Upper Nile we owed to Captain Watson, R.E., who was fortunate enough to observe a transit of 'Venus,' whilst at Gondokoro, in 1872. It resulted from this observation that Khartum lay eight miles to the east of the position assigned to it by Captain Bizemont, a change, sanctioned by the careful surveys made between El Fashr, Khartum, and Dongola by the English engineers working under Mr. Fowler. Good longitudes were few and far between, but latitudes were fortunately very numerous.

As to altitudes, the results were most discordant, and differences of 1,000 feet in a total altitude of 5,000 were by no means rare. The establishment of permanent studies by the French and German African Associations would no doubt render future observations for height more trustworthy. For the present, he thought we were safe in assigning to Tanganyika a height of 2,700 feet, whereas the Victoria Nyanza lay probably at an elevation of 4,000 feet.

After a rapid examination of the principal explorations which had yielded materials for the map, the vast region stretching along the eastern margin of the Victoria Nyanza right away to Southern Abyssinia and Harar was pointed out as the vastest and most promising field of exploration in Eastern Africa.

4. *On Senegal, Gambia, and the Gold Coast. By* Commander V. L. CAMERON, *R.N., C.B.*

SATURDAY, AUGUST 26.

The Section did not meet.

MONDAY, AUGUST 28.

The following Papers were read:—

1. *The Deserts of Africa and Asia. By* P. DE TCHIHATCHEF.
See Reports, p. 356.

2. *On Merv. By* E. O'DONOVAN.

Starting from Kelat-i-Nadiri Mr. O'Donovan travelled to Archengau, and thence northward to Kahka, a considerable walled village of 5,000 inhabitants. His next station was Dushakh, or Chardéh, twenty-five miles distant to westward, and beyond it, some thirty-five miles, the Tekke colony of Méhna. From this latter he started direct for Merv. The ground up to the banks of the river Tejend was flat, partly cultivated, and cut up in many places by the beds of old irrigation canals. The river itself, about fifty yards wide, had cut a shallow ravine some twenty feet in depth. The water was sufficiently low in that month (March) to allow the stream to be forded, though with difficulty. Trees of various kinds grew plentifully along it, and drift wood had accumulated at places in great quantities. The plain beyond was marly and overgrown with tamarisk bushes. The only water met with was a very brackish well at Shahidli, about half-way between the Tejend and Murghab. Some miles further on were the ruins of a large caravanserai at a place called Dash Robat, and then the inhabited oasis was reached, everywhere dotted with groups of beehive-shaped huts, fifteen feet in diameter, and twelve in height. Through its midst the river Murghab flowed, and at a dam at the southern end of the Tekké territory two canals branched off, the Alasha to the west, the Novur to the right. These supply the irrigation trenches of the ground occupied by the Toktamish and Otamish Turkomans, the first settled on the eastern, the second on the western banks of the river. The Merv oasis is some forty-five miles in length from north to south, and thirty-five in breadth. Numerous groves of fruit trees surround the villages. The staple products are corn of various kinds, melons, cows, sheep and goats. Manufactures there are none, save that of hand-made carpets, which are exported to Persia and Bokhara in very limited quantities.

On the eastern margin of the oasis are the ruins of the old cities of Merv. The oldest is named Giaour Kala, and is about 900 yards square. The ramparts are forty feet in height—huge earth-banks in fact. This was destroyed by the Arabs, A.D. 666. The next in age of the cities is named at present Sultan Sanjar. The walls are in a good state of preservation. Their circuit is about 2,500 yards. In the midst of the enclosed space stands the lofty domed mausoleum of Sultan Sanjar. The town was taken and ruined in the thirteenth century by a son of Genghis Khan. The third and latest city, destroyed nearly a century ago by the Bokharians, stands close by, and is named Bairam Ali. A little to the northward are the remains of an extensive entrenchment, called by the Turkomans, Iskander Kala, or the fort of Alexander. These ruins, situated but 1,000 yards apart, are entirely uninhabited. The population of the Merv oasis is estimated at half a million, which is probably not an excessive computation. The two great divisions, the Toktamish and Otamish, are governed by two hereditary chiefs, that of the Toktamish being the senior and taking precedence at the médjlis or general council of the elders of the nation.

The soil of Merv is very fertile, as is also that of the country far and near on every side of it, and were it not for lack of water the entire plain from the Oxus and Merv to the Caspian might be highly cultivated, for the desert is not a sandy one, but of sun-scorched marl.

There is now no central point like the Merv of old. The only rallying point of the Turkomans is at Koushid Khan Kala, a great earthwork on the eastern bank of the Murghab at about the centre of the oasis. Here some 2,000 huts are gathered together, and here dwell the principal Turkoman chiefs.

3. *On the Identification of certain Ancient Diamond Mines in India.* *By* Professor V. BALL, *M.A., F.R.S., F.G.S.*

The vague references to India, as the only then known source of diamonds, by the writers of 2,000 years ago, give place to more definite indications of position in Sanscrit works of the sixth century, and possibly of somewhat earlier dates. In the Barhat Sanhita a list of localities is given, but as the stones from some of the localities therein mentioned were copper-coloured, it is possible that they were not diamonds.

In the Ain-i-Akbari (1590), and also less clearly in Ferishta's History (1425), a locality named Beiragarh is referred to, which can be identified with Wairagarh in the Central Provinces, where the remains of ancient mines are still to be seen.

The following localities mentioned by Tavernier (1665), had not been identified until lately, though various attempts had been made by Colonel Rennell and others since his time. Gani or Coulour is Kollur on the Kistna, Gani simply standing for *Kan-i* or mine of; Raolconda is Ramulkota in Karnul; Soumelpour was on the Koel river in the Palamow district of Bengal.

Kollur would appear from Tavernier's statement to have been the mine where the Great Mogul diamond was found. The same stone is perhaps identical with one mentioned by Garcias ab Horto, who wrote 100 years before Tavernier, but if so it must have been found several centuries before the time (fifteenth century) indicated by Tavernier.

The author referred to several other early authorities, and to the mythical stories which are connected with the accounts of diamond-mining, for the origin of which he proposed explanations.

4. *The Geography and Meteorology of Kansas.* *By* LITTON FORBES, *M.D., F.R.G.S.*

The author, who had had large personal experience in Kansas and Colorado, desired to point out some facts in the geography and meteorology of Western Kansas, which, perhaps, had not received all the attention they deserved. The physical conditions of this State, the most central of the Union, were in many respects peculiar. It was a land of undulating plains, almost as flat to the eye as Holland or Egypt. Its watercourses, its soil, and above all its climate, presented many points of interest. It would be perhaps impossible to find a country of equal extent where the physical changes produced by the advent of civilisation have been so numerous and so important. Not only has the fauna been in great part changed, but the flora also, as well as the amount of rainfall, and the general hygrometric conditions of the atmosphere. Not merely has the number of inches of annual rainfall increased, but it has also been more equably extended over a larger extent of country. The procession westward of the rainfall of Kansas in proportion as settlement has extended westward, is a most important fact. It may be due in part to the planting of timber, but is probably much more directly dependent on the immense acreage under wheat, indian-corn, and other crops, which afford protection to the earth from the sun's rays, and so check a too rapid evaporation. A careful study of the changes wrought in the climate of Kansas by settlement might possibly aid in the solution of certain problems which have long presented themselves in some of the southern colonies of Great Britain. Many parts of South Australia and New South Wales assimilate very much to Western Kansas in soil and climate. Those countries have hitherto been considered as possessing too little moisture for agriculture, and as therefore fit only for grazing purposes. The same was said of Kansas some twenty years ago, but within that time very marked climatic changes have taken place. What settlement has effected in Kansas, it may equally well effect in Australia, with similarly beneficial results. The State of Kansas forms a rectangular parallelogram, which measures about 400 miles from north to south, and about 200 from east to west, and contains over 82,000 square miles. Though to

the eye apparently one vast level plain, it is really a more or less elevated plateau, which slopes eastwards at an appreciable angle. The highest, or western portion of the State is about 4,000 feet above the level of the sea, while the average height of the whole country may be placed at about 2,375 feet. The main watercourse is the Arkansas River, which has a fall of about six feet in the mile. In spite of the absence of hills, Kansas is singularly free from marshland or swamps. This is due in part to the friable nature of the soil, and in part to the natural slope of the land towards the east. What is known as the 'Great Arkansas Valley of South-Western Kansas,' embraces a width of fifty miles, nearly the whole of which is sloping upland. The soil here is a sandy loam, of alluvial origin, and of great depth and fertility. A remarkable peculiarity of the Arkansas River is that it never overflows its banks, but, so to say, underflows them. The water filters through the gravelly stratum underlying the surface-soil of the valley, and may always be found by digging for it.

From a meteorological point of view, Kansas may be said to be divided into three distinct zones, marked off by the amount of rainfall. In the extreme east, the rainfall assimilates itself to that of Missouri, and is ample for all purposes of agriculture. In the middle zone, which may be said to lie in Central Kansas, the rainfall is less, but yet amply sufficient for all purposes of farming or pasturage. The vegetation here is extraordinarily profuse, and is subtropical in character. The third and last zone lies in the western and south-western portions of the State. Here the climate assimilates itself to that of Colorado, and the rainfall is insufficient for agriculture, though sufficient for grazing purposes. It would seem, however, that the limits of the zone of moderate rainfall are constantly proceeding west as civilisation advances westwards. Twenty-five years ago, the frontier of agricultural production was placed at about the 96th degree of Western longitude. Ten years later it had advanced to the 97th, five years later to the 98th, while to-day it may be said to extend to the 100th. Along with this advance the character of the flora of the country has appreciably changed. The 'blue stem' grass and other plants which require moisture have displaced the buffalo or 'gramma' grass which is the natural covering of the great plains. Whether the procession of the rainfall will continue to advance as heretofore, when once it has reached the 100th meridian of west longitude, may fairly be open to question. The prevailing winds from May to September are from the south and south-west. But inasmuch as the western limit of the Gulf of Mexico is in the 98th meridian, it follows that these winds must blow over the arid and thirsty soil of Mexico, and therefore will contain little moisture. Hence this western portion of Kansas must long continue to be an essentially dry country. Much, later on, may indeed be done by judicious irrigation, and something possibly by artesian wells. Cultivation will no doubt in time modify the climate of Western Kansas, as it has modified that of Central. But the process will be slower and accompanied by greater difficulties. The past history of Kansas, however, forbids us to doubt that in time these difficulties will either be overcome, or will have ceased to exist. The people of Kansas are a remarkable class of settlers even for Western America. The settlement of the country has been helped much by excellent natural roads, and by a more than usually energetic and intelligent population. But after all it is really the railway which has made Kansas what she is to-day. It is the absence of this American energy and business enterprise which keeps large portions of our Australian colonies so far behind. The railways brought settlers to Kansas, and developed the country with a rapidity and thoroughness which would otherwise have been impossible. One railway has done it all. The history of the Atchison, Topeka, and Santa Fé railroad is really the history of Kansas. To the energy, the sagacity, the business acumen, and the capital of that corporation, the prosperity of Kansas is mainly due. This is an important fact which should not be lost sight of in some of our own southern colonies, whose physical and political conditions are much the same as those of Kansas were a few years ago.

5. *The Spanish Territories of North America.* *By* E. VON HESSE WARTEGG.

The completion of the new Southern Railroad line across the North American continent to the Pacific coast, within the last two years, opened to geographical explorers and travellers a new field of research and discovery, heretofore rarely visited and very little known on account of the great dangers and hardships of the long and tedious overland voyage thither.

New Mexico and Arizona, centuries ago thickly inhabited by the aboriginal races—the Toltecs and the Aztecs—were afterwards made tributary to Spanish and Mexican rule, until they came under the United States' Government in 1846. Even then these two south-western territories—comprising nearly 240,000 square miles—remained unexplored, some reconnaissances of the United States' military officers excepted, among which are those of Major Powell and Lieutenants Ives and Amory. New Mexico and Arizona, the oldest territories of North America, may therefore be called, with equal reason, the newest; and as they will evidently soon come into prominent notice, the author made them the object of a prolonged journey during the first month of 1882.

Although on the same latitude, and bordering upon each other, they are very dissimilar in their general character, mostly on account of the Rocky Mountain Range and the distribution of the water-supply.

New Mexico is by far the more fertile and more interesting of the two; especially in the valley of the Rio Grande, the principal river of the territory, traversing it from north to south. This valley, in its general character, its population, ancient ruins and aboriginal habitations, its products and the manner of agriculture, possesses a certain similarity to Egypt.

The Pueblo (Town) Indians, inhabiting this valley and the neighbouring high Mesas, are the object of the greatest curiosity to every scientific observer, for they are undoubtedly lineal descendants of the great Aztec race, although some claim them to be of Toltec origin. The author spent considerable time in their fortresses and pueblos, and discovered many highly interesting details regarding their life, their origin, and their relationship to other races. The country around the Rio Grande is full of ancient pueblo ruins, of cliff-dweller houses, burial caves, hieroglyphic inscriptions, and ancient stone implements.

The highly fertile Rio Grande valley forms the nucleus of New Mexican wealth, population, agriculture, and traffic. The old Mexican and Indian inhabitants are doomed, and will soon be driven away by the industrious Northerners. The largest cities, including Santa Fé, the capital, Albuquerque and El Paso, lie in or near this valley. Most of the enormous mineral wealth of the territory is to be found in the mountain ranges on both sides of the river. Towards the south the valley diminishes in extent and fertility, and enters at last a great cactus desert, called the Tornada del Muerto.

The high plateau of the eastern half of the territory contains much arable and pasture ground admirably adapted for sheep and cattle raising. The western half of New Mexico in general character resembles Arizona, which is the most sterile of any State or Territory of North America, with comparatively very little agriculture in some of the valleys, and limited capacity for cattle-raising. The immense tract of land lying between the Rio Colorado and the Rio Gila (these being the two great rivers of Arizona) is nearly destitute of all water. The southern part of the territory is little more than a desert, with occasional fields of giant cactus; the temperature is mild and agreeable in winter, but of excessive and unbearable heat in summer.

The great strength and the principal resources of Arizona are her enormous mineral wealth, including very rich deposits of gold and silver; also her scenery, which, especially in the northern part and along the Colorado cañons, is unequalled in grandeur and weirdness. It will require more railways and settlers to develop the resources of Arizona, and overpower the Navajoes and Apache Indians, whose ravages are still occasionally severely felt by the settlers.

6. *The Dominion of Canada, especially with regard to the Geography of the North-West Territory.* By CYRIL GRAHAM, *C.M.G., F.R.G.S.*

TUESDAY, AUGUST 29.

The following Report and Papers were read:—

1. *Report of the Committee appointed for the purpose of promoting the Survey of Eastern Palestine.*—See Reports, p. 296.

2. *On some unexplored or little known parts of Persia.* By Colonel Sir OLIVER ST. JOHN, *R.E., K.C.S.I.*

This was an account of a journey by a partially unexplored road from Bushire to the interior, mainly interesting as being that by which the Persian army brought its guns to the coast in the war of 1856–7, and as passing through the country occupied by the Kashkais, the principal tribe of Toork nomads in Fars. Though less difficult than the ordinary route, it is rarely if ever used by caravans, owing to the want of water on one or more stages, and the liability to attack by the nomads. Leaving Bushire on March 8, the author, who was accompanied by Lady St. John, marched through Ahram to Khormuj at the foot of the mountain of that name, well known in the Persian gulf as a prominent landmark. Here the travellers were entertained by the chief of the district of Dashti, of which Khormuj is the principal place. This part of the country had suffered little from the famine then raging owing to the staple diet of the people being dates, of which the harvest had been abundant, but the horses, the breeding of which used to be a source of considerable profit, had nearly all perished from bad or insufficient nourishment. Leaving Khormuj, Sir O. St. John marched to Laweh, whence a difficult pass, called the Tang-i-sehdar, 'The Defile of the Three Gates,' brought him in two days to Kalima, only twelve miles from Ahram as the crow flies. The detour made was about 70 miles, and was necessitated by the impossibility of getting loaded mules through the pass which directly connects Ahram and Kalima. This latter village, 1,000 feet above the sea, is in the lowest of the terrace-like valleys intervening between the highlands and the coast. Two long marches brought the party to the large village of Farashband in the wide grassy valley, 3,000 feet above the sea, which occupies the second of the terraces, and forms the winter grazing-grounds of the nomad tribes of Toorks called Kashgais, from Kashgar in Central Asia, whence their ancestors emigrated into Persia, in the train of Jangis Khan or one of his successors. From Farashband the party marched N.W. along the valley to beyond Jereh, where they were entertained for several days by Ali Kuli Khan, the Ilbegi, or second chief of the Kashgais. Concerning the manners and customs of this important and powerful tribe many details were given, which, however, do not permit of compression. On leaving the Ilbegi's camp, a march of fifteen miles brought Sir O. St. John to the high road between Bushire and Shiraz, which is well known.

3. *On the various means of communication between Central Persia and the Sea.* By Lieut.-Colonel J. W. BATEMAN CHAMPAIN, *R.E., F.R.G.S.*

The author began by drawing attention to the very defective means of locomotion in Persia, and briefly described the troubles and inconveniences which travellers in this country are compelled to encounter. The Government pays little or no attention to the communications; and the caravanserais, causeways, and bridges which exist are nearly always the work of private individuals, who leave them after completion to take care of themselves.

Persia is a country of about 600,000 square miles in extent, but with one exception boasts of not a single navigable river or canal. It may be described as a plateau averaging from 3,000 to 5,000 feet above the level of the sea, and although

a great part is an unmitigated desert, there are in many parts valleys and plains of astonishing fertility. The general scarcity of water reduces the capabilities of the country and accounts for the sparseness of the population.

The trade is, however, considerable, and might be vastly increased by the improvement of the roads. After indicating the nature of the ordinary exports and imports, the author proceeded to point out how the trade from Russia is gradually superseding that from British sources, not only in the north, as might reasonably be expected, but also in the southern markets of the empire.

The difficulties of the several trade routes from the Persian Gulf to the interior were then briefly described, and attention was directed to the natural facilities offered by the Karun river as a means of communication with the provinces of Shuster, Dizful, and other parts of Persia as yet scarcely touched by the European trader. Mohammerah, as the port of this route, possesses remarkable advantages. It commands two distinct means of communication with the Gulf, the Shat-el-Arab, and the Khor Bamushir, and the climate of the place is excellent. If trade by the Karun route were properly fostered by the Persian Government, Mohammerah might rival in importance its neighbour, the Turkish port of Bussorah. Reference was made to Captain Selby's exploration of the Karun in 1842, and also to Mr. Mackenzie's journeys between Shuster and Isfahan. This route has been travelled over again last November by Mr. Baring of Her Majesty's Mission and Captain Wells, R.E., who have written very graphic accounts of their trip. Mr. Mackenzie thinks that the route between Shuster and Isfahan is far easier and better than the one now followed to the latter city from Bushire, through Shiraz; and he explains how advantageous it would be to British commercial enterprise were this route opened up. Captain Wells, on the other hand, considers the difficulties of the direct road to Isfahan to be very formidable. In any case the establishment of regular steam navigation on the Karun would open out new fields, and commercial operations would gradually but surely extend further inland.

The only physical obstacle to the regular running of steamers on the river occurs at Ahwaz, and is fully explained in Captain Wells's report and on his plan exhibited. Means are suggested for overcoming this difficulty by cutting a canal some 2,350 yards in length from above to below the rapids—a work which presents no difficulties and would cost but little. The Persian Government has, however, so far shown itself distinctly opposed to the development of trade in this direction, and, actuated by a very short-sighted policy, refuses to allow foreign steamers on the river unless heavy, in fact prohibitive, taxes be paid as river and port dues. A little judicious and well-timed diplomatic pressure might probably remove this antagonistic feeling; and, in the interests of Persia and with the object of promoting and extending British trade and influence in these regions, the author believed that friendly action should be taken by the British Government.

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4. *On Tongkin and the new Approach to Yunnan.* *By* D. BOULGER.

SECTION F.—ECONOMIC SCIENCE AND STATISTICS.

PRESIDENT OF THE SECTION.—The Right Hon. G. SCLATER-BOOTH, M.P., F.R.S.

[For Mr. Sclater-Booth's Address, see next page].

THURSDAY, AUGUST 24.

The following Reports and Papers were read:—

1. *Report of the Anthropometric Committee.*—See Reports, p. 278.

2. *State of Crime in England, Scotland, and Ireland in* 1880. *By* Professor LEONE LEVI, *F.S.A.*—See Reports, p. 375.

3. *Report on the workings of the proposed revised New Code, and of other legislation affecting the teaching of Science in Elementary Schools.*— See Reports, p. 307.

4. *Statistical Account of Railway Accidents for the year* 1881.[1] *By the* REV. DANIEL ACE, *D.D., F.R.A.S.*

During the year there were reported sixty collisions between passenger-trains and others, by which it would appear that of all modes of travelling that of railway is the safest. The casualties are few compared with the millions of passenger-journeys included in the reckoning of accidents arising out of the use of other vehicles, such as vans, carts, and waggons.

Railway statistics show a comparatively small sacrifice of life in that class of accidents over which the victims cannot be supposed to have any control. It is here that the test of efficiency has to be applied, and although any sacrifice of life is to be regretted, the fact that only 23 passengers were killed by want of caution, or misconduct, or circumstances under their own control, out of the myriads who travelled on the railways of the United Kingdom last year, must be held to show a marvellous degree of skill and care in the working of the traffic.

Upon examination of the statistics it will be evident that the suicides were 64, thus almost trebling the number of passengers killed by railway accidents pure and simple. But there were accidents to passengers from other causes than accidents of trains, including, besides accidents from their own want of caution or misconduct, those happening to persons passing over level crossings; these amounted to 83 persons killed, and 32 injured. Level crossings, where they exist, are little better than man-traps.

A feature by no means to be overlooked consists in the nature of accidents which befall the companies' servants. That more than 500 of the subordinates should be killed in a single year is a serious matter, and must exhibit a very high death-rate if compared with the entire number on the staff, of whom signalmen should be protected from over-work and liberally remunerated. There were in the division mentioned 552 persons killed and 1,132 injured. Altogether the number of persons killed and injured on railways during the year ending De-

[1] Published *in extenso* by Hannam, Silver Street, Gainsborough, Lincolnshire.

cember 31, 1881, as ascertained by the Sixth Section of the Railways Act, amounted to 1,149 persons killed, and 8,676 injured. A Government inspector remarked when observing the fatality of railway servants, 'that it was a scandal that sixteen consecutive hours of work should be exacted from any man upon whose vigilance depends the safety of the public,' and whose momentary forgetfulness might occasion a fatal catastrophe.

5. *Agricultural Statistics, Tenure, and Aspects. By* WILLIAM BOTLY, *M.R.A.S.E.*

The author cited figures showing that the quantity of food brought to Europe in the past year exceeded 8,000,000 tons, at a cost of 35,000,000*l*. sterling, for meat, and 85,000,000*l*. for grain; of the 35,000,000*l*. for meat, the United Kingdom paid 26,612,000*l*.; being at the rate of 40 lbs. weight of imported meat to each inhabitant. Our consumption of grain is 607,000,000 bushels, our production, 322,000,000 bushels.

As regards produce per acre, England compares favourably with most other countries, though admitting we have some minutiæ to learn from them, particularly in that of growing more fruits and vegetables, as a new and profitable departure in agriculture. With reference to the landholder, fewer restrictions as to cropping, &c., must be observed,—security of tenure, an equitable rent, with compensation for all unexhausted improvements. The tenant to have practical knowledge, ample capital, skill, and enterprise; he must be a farmer—not a high-flying, sporting, racing, and betting man. The labourer must have a decent cottage, and garden-ground for vegetables, employing himself and family after hours, making him more respectable and far happier than spending his time and hard earnings in smoking and drinking at the alehouse.

With those reasonable and equitable adjustments, a good market at our own doors, with more favourable seasons, the author spoke hopefully, concluding thus: 'I have no doubt as to a brighter future for agriculture. We stand A1 in our yield of wheat, and are the largest consumers of meat in Europe.'

FRIDAY, AUGUST 25.

The PRESIDENT delivered the following Address:—

On Local Government in Rural Districts.

IN selecting Local Government in the Rural Districts for the subject of my address I have no wish to transgress the rules of the Association, which eliminate controversial politics from the materials for our discussions; on the contrary, I am anxious to seize an opportunity which thus presents itself of securing for what is, or ought to be, a non-political question, the chance of being considered and examined in a non-political atmosphere.

There are also some circumstances and arrangements to be found in the local government of the county of Hampshire, commonly called the county of Southampton, which seem peculiarly worthy of notice by way of illustrating what is or may be the state of things under the existing law and practice.

Those who desire to enter into the question of local government historically analytically, and comprehensively, will find it dealt with *ab ovo*, and in an exhaustive manner, by my friend the Warden of Merton College, Oxford, in an excellent essay published by the Cobden Club (in their volume for 1882). Such is not my intention. I wish rather to take it up on the assumption that the actual facts of the case are more or less familiarly known to my hearers, and to offer some observations, the result of my own knowledge and experience, which may direct attention

to certain aspects, hitherto little regarded, of what is undoubtedly a difficult and important subject, but one as to which, perhaps, we shall find, on examination, that the difficulty and importance have been exaggerated, confused, and obscured by misleading conceptions and imperfect appreciation of its bearings.

Many people, and those not always the best acquainted by experience with the working of our local institutions, have committed themselves a little hastily to a condemnation of the chaotic condition and mischievous working of the existing system; and these are just the class of thinkers who, from the bias of their minds, are impatient of anything short of scientific rearrangement and completeness, the bureaucrats of a centralising government, or the fanatics of political philosophy. The urgent need of a 'root and branch' change, again, has been exaggerated by the jealousies and rivalries of political partisans.

In singular contrast with these it is interesting and profitable to notice how little the local authorities who are engaged in the administration of the rates, or the ratepayers themselves, have responded to the attempts which have been made from time to time, and particularly of late years, to get political capital out of these questions. Common sense and practical knowledge teach them to mistrust platform oratory on such humdrum subjects, which attract little real interest amongst politicians; while they know from their own experience that many of the complaints (not all) are beside the mark, and instinctively feel that some of the remedies proposed may turn out worse for their interests than the evils complained of.

Ambiguous language in this, as in many other things, is the cause of a number of current fallacies. Local government means quite a different thing as applied to, firstly, rural, secondly, semi-rural, and thirdly to urban communities; but this is forgotten in the eagerness for uniformity and simplicity of system. The genius, however, of the English people is not favourable to a highly scientific organisation like that of the French, who have much more of the form, with less of the reality, of local self-government than is to be found in this country; and even in France it required no less formidable an instrument than the great Revolution to obliterate the old names and landmarks which had prevailed during the monarchy. The demand for municipal government in our counties, which is derived, perhaps, from the present French system, involves the fallacious assumption that the sort of administration which is needed for towns is required, or even possible, in rural districts.

If we find a thorough system of municipal government established for cities and towns, and provisions of law in constant and useful operation for the gradual introduction of the same into growing or inchoate urban communities, (which is really the case), it may fairly be argued that the rural and scattered population of the counties, whatever may be needed in the way of improved representation on their governing bodies, do not really require, and are not, in fact, in a position to profit from such local government as is primarily adapted to the wants of towns and cities, and such as is within their reach as and when the want of them is experienced.

As population increases in compactness and wealth it begins, of course, to require municipal government for many purposes apart from the primary objects of police supervision and the maintenance of order. The householders in common council together find they can provide better and more cheaply through such means for their common health and wealth, for the cleanliness and convenience of their dwellings, and for the luxuries which rapidly become the necessities of town life, such as water-supply, lighting and scavengering of streets, sewerage, building regulation, fire-prevention, &c. These are objects which householders in rural districts must provide separately for themselves. Common to both are (1) police supervision, in so far as that service is borne or assisted by local taxation and management; (2) road repair, though of a less expensive sort in rural districts; and, (3) above all, the poor law administration, which forms the real difficulty in harmonising local government for town and country, and which stands in the way of those who fancy it easy to reconcile conflicting or intermixed local government areas.

The Poor Law system, as we now know and have experience of it, was forced

fifty years ago on the attention of Parliament and the public by circumstances into which we need not enter. Under it the fifty-two counties of England and Wales, containing about 15,000 parishes, have been divided into about 650 unions. These were marked out and settled in a somewhat bureaucratic and centralising spirit, no doubt, but still with due regard to the essential object of convenient local administration, a convenience which could not be found in symmetry with county areas. County boundaries were, accordingly, disregarded to such an extent that fully one-third of the unions overlap the borders of two, or even of three, counties. The desired objects were, nevertheless, for the most part attained, and may be comprehensively stated under two heads: first, the interests of the poor—the possible recipients of relief—as regards the accessibility of the workhouse; and secondly, the interests of the ratepayers as regards economical management and equitable grouping of parishes in proportion to their greater or less rateable value, and to their more or less pauperised condition.

To whatever criticism the mode in which these unions were laid out may be open in detail, and although there is ample legal power for their alteration and amendment, there can be no question but that they are so far stereotyped, as a great national settlement, that they do not admit of comprehensive re-settlement: not because of any difficulty in drawing an area map of the kingdom on different lines or principles, or with more regard to county and other local boundaries; but because the local interests which have grown up during half a century, and which have been recognised by innumerable Acts of Parliament, are bound up with them, and are of far greater importance actually, and still more from the point of view of those locally interested, than any importance which can be quoted as attaching to the county, or to central government considerations.

Parliament has so far recognised this, and so far committed itself to the union as the administrative area of the future as contradistinguished from the county, that it has from time to time attached new functions to the guardians and new importance and value to the district within which they hold sway. Briefly, they are as follows: 1. Each union was composed originally of many parishes, which retained a certain amount of independent action, and, in particular, the right and duty of the valuation of property and its assessment to the local rates. These functions were transferred to the guardians of the union by the Union Assessment Committee Acts. 2. Each parish was originally made responsible for the cost of its own pauperism; but, by the Union Chargeability Act, not only was the expense spread equally, or, rather, ratably, over the union, but the management and control of the board of guardians as a whole over the pauperism of the union became greatly more effective. 3. In process of time, as the need for sanitary legislation became recognised, each union was made a separate and complete administrative area for sanitary purposes, with officers and machinery for carrying out the Public Health Act (which wisely discriminates between the rural and urban districts as regards the stringency and character of its provisions). 4. Each union has been more recently constituted a centre of administration under the Education Act, and is charged with the important duty of enforcing compulsory attendance at elementary schools, and of paying school fees for the poor under certain circumstances. Here, again, it may be observed that Parliament has specially provided for the rural districts a machinery different from that which is adapted to the populous places where the School Board system may more properly prevail. 5. Each union has functions assigned to it under the Registration Acts, and is charged with the important duty of enforcing primary vaccination over the whole kingdom. 6. Lastly, by the legislation of 1877–8, the entire management of the highways of the rural districts has been placed within the power of the guardians, and the areas of highway management may become identified with those of the poor law unions.

It may fairly, therefore, be laid down, that local government for the rural districts is actually or potentially provided by these means—that it is already too stereotyped to be shifted without such a wrench as would be of revolutionary severity, and too important, even if that were otherwise, to be subordinated or interfered with for any practical or theoretical objects which have as yet been assigned as a reason for the constitution of a system of county government.

County government has a very portentous sound, and the idea of it is plausible and attractive; but when it comes to be examined, we find there is little meaning in it as at present exercised, much that is of doubtful expediency in the proposals for its extension, and no slight fallacy in the idea that it ought to be, or indeed can be, converted into a system of 'municipalities for counties.'

As to the facts, the counties appear, by the Statistical Abstract, to levy for county and police purposes about one and a half millions annually, of which total sum it is probable that the larger moiety is required for the latter and secondary object. It is, no doubt, an anomaly that this money should be levied and expended by persons who, though deeply interested in public economy, are not the elected representatives of the ratepayers. Meanwhile it may be noted that the sum of nine or ten millions, *i.e.* four or five times that amount, which is required for poor law, sanitary, and highway purposes, is exclusively raised and administered by persons annually elected by and responsible to the ratepayers.

If, again, we further analyse the county expenditure, we find that as regards the police force, for which the larger amount is levied, the county authorities, like the town councils in boroughs, are only partners with the central government in respect of the pay and management, and are very much under the control of the Home Office for both.

Of the county rate proper, which may be taken in round numbers at about 750,000*l.*, it is probable that about one-half is required for the repayment of loans raised to meet capital expenditure which has been made obligatory by Parliament under various statutes for the building and maintenance of prisons and lunatic asylums. Of the remainder, some is expended in discharge of duties imposed by statute in connection with coroners' inquests, and in the salaries of the coroners themselves. Heavy expense is likewise incurred under the Cattle Diseases Prevention Acts, the Sale of Food and Drugs Act, and many other statutes; so that the margin of debateable expenditure on salaries of county officers, and on the repair of buildings and county bridges, amounts to a comparatively insignificant sum in comparison with the enormous amounts which are directly dealt with by the agency of the Board of Guardians, a body thoroughly representative of ratepayers.

Those who desire to set up the county as an administrative machine for all purposes, and in relief of our overworked House of Commons, forget how little meaning the term and name of a county now has, except for political representation and for the administration of justice. What measure, indeed, for county government reform could be devised which could provide machinery uniformly applicable over such widely different areas, in point of size and circumstances, as Devonshire and Rutland; or for Lancashire and the West Riding, spotted over with numberless municipalities and local board districts, in common with Cambridgeshire or West Sussex, with their sparse population of small village communities? Further, the notion that county parliaments are, as county municipalities, to carry on public business, to vivify local life, and to relieve the overloaded shoulders of the House of Commons, is based on a triple fallacy. First, it is assumed that control exercised by such bodies over the subordinate areas of unions or highway districts and parishes would be welcomed in exchange for the control of the central government; whereas they would probably be more unpopular, and certainly less effective. Secondly, it is forgotten that the requisite machinery for such an organisation and control could not be brought to bear without great cost and a multiplication of permanent county officers in continuous session at head-quarters. And thirdly, it is impossible to believe that the public opinion of the country would ever deliberately suffer the parliamentary function to be discharged by sixty or seventy local centres, taking different, and probably conflicting views of duty and policy. It would indeed be Home Rule for counties, with all the evil omen attaching to that phrase. Every consideration of prudent statesmanship points to the conclusion that county government, if reformed and endowed with an infusion of the representative element, must be confined to the limited functions now exercised by the Courts of Quarter Sessions, together with such new duties as it may be found possible to devise without interference with the real and, on the whole, satisfactory work of the guardians, waywardens, and sanitary authorities,

which already are, to all intents and purposes, the municipalities of the rural districts.

How nearly the system thus sketched out *à priori* may be brought into actual working under the existing law and practice, can be illustrated very well and appropriately by the state of things which prevails at this moment in the county of Southampton.

The twenty-five poor-law unions into which Hampshire was divided fifty years ago, have been, with the exception of three or four parishes, only one of which is of importance, brought within the county area. The magistrates with wise forethought identified, many years ago, their own magisterial divisions with those of the poor law unions, and more recently they established, under the Acts of 1862 and 1864, highway districts conterminous with the same administrative areas. Quite recently the guardians of several of these unions have taken on themselves, by a process permitted and encouraged under recent legislation, the office and duties of highway authorities. We thus have, in the county of Hants, twenty-five subordinate areas, completely exhaustive of the county map, the governing bodies of which are poor law guardians, sanitary authorities, valuers and assessors of real property, waywardens of the highways, supervisors of public vaccination and of elementary education; and they discharge these multifarious duties for the ratepayers, to annual election by whom they owe their existence, and in the general interests of the public, on whose behalf Parliament has imposed them.

These representative governing bodies levy and expend for the purposes above-mentioned a sum of about 300,000*l.* annually, which is equal to a rate of about 2*s.* 3*d.* in the pound on a ratable value of about two and a half millions. The Court of Quarter Sessions, on the other hand, levies annually about 35,000*l.*, in the shape of county and police rates, in nearly equal moieties. In other words, the ratepayers control directly about 2*s.* 3*d.* in the pound, while the magistrates expend about 4*d.* under these two heads. But, of the moneys levied for the county, apart from the police, one-third goes to the payment of debt; so that the other items of expenditure, including a heavy contribution to the cost of the main roads, is covered by a rate of about 1¼*d.* in the pound. The ratepayer's grievance being thus exhibited in its true proportions, the problem for solution becomes difficult in proportion to its minuteness. On the one hand, it is undesirable to establish an electoral machinery more important and extensive than in proportion to the duties which have to be discharged; and, on the other hand, any attempt to add new obligations, or to establish a centralised county authority, having a status and jurisdiction paramount over the elective guardians, will be certain, as it becomes appreciated in all its bearings, to excite jealousy and alarm amongst those whose grievances it is presumably intended to redress.

If I may venture, in conclusion, to draw a moral, it would be by way of caution and advice to those who may be desirous of taking up this subject, to inform themselves exactly what alterations and improvements in our system of local areas and administration are permissible under the existing law, and then to inquire why they are so rarely effected. The fact is, that no such changes can be made without touching vested money interests according as the effect will be to increase or diminish the ratio of rateable value to pauperism; and this difficulty is aggravated where loans have been raised on the security of the rates. Besides this, the disturbance of local institutions such as must accompany departmental or legislative activity is always unpopular; and unpopularity in these days enormously facilitates the proceedings of the Parliamentary Obstructionist. The fate which has attended all the endeavours hitherto made to reform county government bears melancholy testimony to the influence of that formidable personage.

It may be useful to give a few figures in particular illustration of the sums devoted to different heads of expenditure in the county of Hampshire, as regards the union area and the county area respectively.

Analysis of Expenditure in Poor Law Unions in the County of Southampton in the year ending Lady Day 1880.

Total Relief to the Poor	Payments for or towards the County, Borough Rate, or Police Rate	Payments by Overseers to Highway Boards under 27 & 28 Vict. c. 101, s. 33	Contributions by the Overseers to the Rural Sanitary Authority for General Expenses (if any)	Contributions by the Overseers to the School Board (if any)	School Attendance Committee Expenses (if any)	Payments on Account of the Registration Act, viz., Fees to Clergymen and Registrars, Outlay for Register Offices, Books, and Forms	Vaccination Fees	Expenses allowed in respect of Parliamentary or Municipal Registration; and Costs of Jury Lists	Payments under Parochial Assessments Act and Union Assessment Committee Acts	Money Expended for all other Purposes	Medical Relief	TOTAL EXPENDITURE
£	£	£	£	£	£	£	£	£	£	£	£	£
205,529	60,887	26,300	4,153	17,176	1,393	2,053	1,956	1,576	889	15,433	10,430	335,347

Particulars of Expenditure out of the County Rate by the Court of Quarter Sessions for the County of Southampton in the year ending March 31, 1881.

Pensions	County Bridges	Main Roads	Coroners	Salaries, County Officers	County Debt Repayment, Principal and Interest	Reformatories and Industrial Schools	Lunatics	County Hall, &c.	Printing and Stationery	Miscellaneous	Cattle Disease
£	£	£	£	£	£	£	£	£	£	£	£
625	607	4,658	967	968	5,518	598	1,027	321	683	714	983

NOTE.—Other large items of expenditure are met, in whole or in part, by fees received, and by repayment from the Government.

I have endeavoured in this address to state shortly, and as far as possible abstractedly, the conditions of an interesting problem in Political Science, without entering into speculative proposals for its solution, which belong rather to the province of debatable politics unsuitable for this occasion. I may, however, remark that the County Boards Bill, introduced by me on the part of the late Government, was designed on the lines above indicated, and that great care was taken in framing it to provide functions for the new authority sufficient to justify its existence, but not unduly intrusive on the functions of the unions and other local bodies. I may also point to the numerous measures of local government improvement which were passed into law by the late Parliament, as illustrating my own readiness to initiate well-considered changes and reforms. What I earnestly desire is that further legislation dealing with various branches of the subject (the need for which can hardly be exaggerated) shall be prepared and carried out in a similar, that is, in a sympathetic and not in an iconoclastic spirit.

The following Papers were read:—

1. *On the Revenue from the Taxation of Alcohol. By* GEORGE BADEN POWELL, *M.A., F.R.A.S., F.S.S.*

At the present moment the question of raising revenue from the taxation of alcohol is of peculiar interest, not only as affecting general principles but also their practical application.

There is no better method of raising revenue than from the consumption of alcoholic drinks. It is, however, true that much alcohol is used for most proper purposes, as, for instance, in various manufactures, and even in consumption, wherever it is beneficially used as a food or as a medicine. There is too great a tendency to mix up with this the temperance question; and consequent discussion is usually far too intemperate in character. There is no doubt that the calm scientific view tells us a nation may consume much alcohol, and at the same time enjoy the highest moral and material prosperity. It is not the use, but the abuse, of alcohol which destroys both these phases of national prosperity.

In these islands we spend 120,000,000*l.* sterling in the year on alcoholic drinks, but no less than one quarter of this is a contribution to the general revenue.

This source of revenue, however, is failing year by year (see table appended). Mr. Gladstone tells us the only balance he can discover is that people are drinking a little more tea and increasing greatly their habit of putting by savings. I wish to put forward two further explanations: (1) the great growth latterly in substitutes for duty-paying drinks—as of chicory for coffee, starch for cocoa. and so forth; (2) the enormous increase in recent years in the consumption of 'bottled waters.' If we tax foods at all we should tax more especially those which are luxuries.

In future years we shall probably continue to derive a considerable income from the taxation of alcohol, but it will not be so large as that we now obtain. It does not seem probable that this less income will be balanced by any absolutely equivalent decrease in the crime and pauperism that become charges on the general revenue. We shall have in some other way to obtain at all events some increase from other sources to balance the larger part of this falling off.

Year	Gallons of Spirits consumed per head of population	Revenue from Alcohol in millions sterling	Revenue per head of population in shillings	Revenue from Tea and Coffee in millions sterling	Revenue from Tobacco in millions sterling
			s. *d.*		
1866	4·	23·	15 6	2·9	6·3
1867	4·1	24·	16 5	3·0	6·5
1868	3·9	24·	15 10	3·1	6·5
1869	3·9	25·	15 10	3·0	6·5
1870	4·	25·	15 10	3·0	6·6
1871	4·1	26·	16 8	3·6	6·6
1872	4·4	28·	17	3·5	6·8
1873	4 6	30·	18 7	3·4	7 0
1874	4·7	32·	19 6	3·5	7·3
1875	4·8	33·	19 9	3 8	7·4
1876	4·9	34·	20	3·9	7·7
1877	4·7	35·	19 7	3·9	7·8
1878	4·7	35·	19 3	4·2	8·
1879	4·3	33·	18 5	4·4	8·5
1880	4·3	32·	16 10	3·9	8·6
1881	3·9	30·5	16 7	4·1	8·7

2. *On the Taxation of Alcohol.* *By* Stephen Bourne, *F.S.S.*

The large share which the taxes on alcohol have in producing the public revenue—more than 30,000,000*l.* out of 86,000,000*l.*, or thirty-five per cent.—renders the subject attractive to the economist, the statesman, and the statistician. At the present moment two circumstances combine to deepen this interest. The one is the necessity for increased taxation to meet the expenditure upon warlike operations, the other the change which is taking place in public opinion on the subject of temperance and abstinence. The recent addition to the Income Tax for the first purpose in the form of 3*d.* extra being deducted from the ensuing quarterly or half-yearly payments, or 1½*d.* on the whole year's income—levied and spent

within the six months—renders it, in fact, a tax of 8*d.* instead of 5*d.* for the half-year—an increase of 60 per cent.

Were this principle applied to the 18,500,000*l.* raised on spirits, it would produce 5,500,000*l.* for the half-year. It must be admitted that this is an article of luxury—one that can be done without—and therefore that its payment is entirely voluntary. It must also be borne in mind that at least one-half of the taxes accruing from drink are expended by the State in preventing, punishing, and repairing evils the result of that drink being consumed; so that on every consideration the only limit to such taxation should be that which, being over-passed, would encourage illicit manufacture or importation.

Wine, which produces 1,300,000*l.*, at present stands in a somewhat different light, and when unfortified, is the most natural and least injurious of all intoxicating liquors. Yet these duties are to be readjusted for political and economic reasons, and in so doing might be fairly made to yield 500,000*l.* more, for at present the alcohol in wine pays at the rate of about 6*s.* on the proof gallon, while spirit pays 10*s.* It is quite right that alcohol should be more highly taxed when produced in a concentrated than in a diluted form.

Beer partakes of the attribute of wine in its too low rating on the alcohol it contains—only 1*s.* 9*d.* per gallon—and to bring it up to a right proportion should be at least doubled. Yet as the poor man's drink, and from long usage, it might not be possible to do this at once, although it should certainly be increased by fifty per cent., or, for simplicity of calculation, from 6*s.* 3*d.* to 10*s.* per barrel, thus raising some 4,500,000*l.* more.

For various reasons these new or 'consumption duties' should be charged on the retailers, who are all licensed, and therefore under the surveillance of the authorities. It might be paid by them concurrently with or following upon the sale of the articles, and their thus having realised their value. This is a somewhat novel mode, but analogous to that of the income tax, which is not received until after the income has been accrued and has even been spent. The nature of the business requires a supervision which in other trades would be deemed inquisitorial, and which for its right conduct might well be combined with the collection of the duties; indeed there are many reasons why this double rating would be desirable in the interests of the Revenue.

From these several sources the whole income to the State from alcohol, which, including licences, now exceeds 30,000,000*l.*, would amount to some 14,000,000*l.* more. This gives an average contribution by each individual of 8*s.* per annum, or say 2*l.* for each family—scarcely more than the price of a glass of beer per day for its head—by omitting which he might save the increased tax. Or, to take another illustration, seeing that on 120,000,000*l.* a year, which is estimated to be spent on intoxicants, the 14,000,000*l.* would be but one-ninth more, the moderate drinker by dispensing with this portion would only be making a fair sacrifice to the needs of his country, whilst the excessive consumer would be greatly benefited by this partial restriction in the extent of his potations.

Whether, therefore, such a scheme should prove a financial success in raising the extra money—all of which, it is probable, will be wanted for Egyptian outlay—or from the check it would give to consumption fail to yield thus much, it is every way desirable. In the latter case it would achieve a moral success far outweighing all disadvantages, really saving to the country that proportion of its income which, though received with the one hand is disbursed with the other, to meet the results of the very consumption which produces the revenue.

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3. *The Influences of the Beer Duty.* By H. STOPES, *F.G.S.*

Two years' practical experience of the Beer Duty that replaced the Malt Tax shows the direct gainers to be:—

1. The National Exchequer, Excise branch.

2. The lowest section of the labouring classes, living in houses of a less value than £10 and £15 per annum.

3. The sections of the community that gain profit from other material than malt and sugar now used in brewing.

The direct losers are:—

1. Farmers.
2. Brewers, especially small brewers for sale.
3. Maltsters.

Indirect losers:—

Landowners and the numerous sections of the people who more or less directly depend upon these losers.

Experience is insufficient to accurately estimate the gains and losses.

The points established are:—

1. The present duty exceeds the old tax.
2. The loss presses heavily upon men ill able to bear it, viz. farmers, smal brewers, and maltsters.
3. The moral and social disadvantages of the 6*s.* and 9*s.* licences, and the desirability of their suppression.
4. The advantages of the 'free mash tun.'

I. The present duty exceeds the malt tax by 2*s.* per quarter at least. Mr. Gladstone admits this, and it is more clearly shown by the Parliamentary returns moved by Mr. Watney, giving details of the brewing trade to September 30, 1881.

The old duty amounted to 22*s.* 8*d.* per quarter. The duty paid by all brewers making over 100,000 bls. of beer exceeded 24*s.* per quarter. By the two largest brewers it was 25*s.* 6*d.* per quarter. By the smallest it was 23*s.* 9½*d.* This class used 667,440 quarters materials; the three largest brewers used 691,038 quarters materials. The duty on the latter amounted to £871,066 8*s.* 9*d.*, on the former to £792,718 15*s.* 3*d.*; if the bulks of material were equal, then the large brewers would pay £50,277 1*s.* 9*d.* more duty than the smaller ones. The apparent loss to the revenue of £92,000 per annum is accounted for by the material, exceeding 250,000 quarters, used by the 110,000 6*s.* and 9*s.* licence-holders, paying only £46,000 instead of £300,000 if material paid as much as formerly, and also by the decrease in beer made last year upon the quantities brewed during the preceding six years.

II. Farmers know now practically that the destruction of the monopoly in barley has lowered the average price several shillings per quarter. No reasonable change in the law can alter this excepting a return to the former regulations and malt duty. Protective tariffs on maize, rice, and sugar will not effect it. This loss at a time of depression is insupportable to many farmers.

Small brewers are disappearing rapidly, and the whole trade is depressed. In 1880 there were—

	Brewers making over 500,000 bls. of beer	over 100,000 bls.	over 1 000 bls.	Small brewers and beginners	Total
1880	4	61	2,205	18,953	21,223
1881	3	56	2,103	14,948	17,110
loss in one year	1	5	102	4,005	4,113

—a remarkable loss, almost entirely of small brewers. Decreased volume of business simply shifts back larger brewers a step lower. This diminution of numbers is a striking proof of losses to small brewers, caused by the beer duty adding directly to their burdens, and the 6*s.* licences depriving them of many lucrative customers, want of knowledge being the primary cause. The materials used by the 14,948 small brewers, if used by the three largest would have produced 166,360 bls. more beer, giving a gross profit to Government of 50,277*l.* 1*s.* 9*d.*, and to the brewers of 150,000*l.*

Maltsters lose heavily also, but no statistics concerning them are now available.

III. Class legislation is usually defective. Brewers now pay heavier duties. Ignorant labourers entirely escape after using 2 bushels of malt; they make very bad beer duty free, and spoil much costly material. The stimulus given to the truck system is also pernicious. Scientifically, cottage brewing is a mistake. These licences should be suppressed or material used by their holders should pay equally with that under all other licences.

IV. Brewers with a free mash tun can make better beer more scientifically at less cost; natural laws regulating production prevent adulteration. Maize and rice are not adulterants, beer brewed from them being identical with, and as pure as malt beer. If the duty was reduced to its old level, the public would get better beer at less cost than at present. If farmers succeed in securing the protective mash tun, the advantages to themselves will equal those they have gained by the repeal of the malt tax, and the general community will lose more.

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4. *The North Sea Fisheries. By* O. T. Olsen, *F.R.A.S., F.R.G.S.*

The author, who has laboured among the fishermen of the North Sea for nearly twenty years, clearly points out several very important facts in connection with these fisheries. He describes by name forty different fishing-grounds, where all kinds of marketable fish are caught. He also calls attention to a very extensive oyster-ground nearly 200 miles in extent and from thirty to seventy miles in breadth, containing inexhaustible oyster-beds, for which he recommends steam trawlers or dredgers. Reference to the chart published by him will show the situation of these fishing-grounds, and a very elaborate description of these banks is given in his 'Fisherman's Seamanship.'

With regard to the fish itself, where, when, and how caught, bait, food, when in season, time of spawning, number of eggs, and the set of the tide in the North Sea, this is graphically described in the Piscatorial Atlas, nearly ready for publication.

The fishermen of the North Sea must be an intelligent class of men, with a very clear conception of things pertaining to their trade, as their observations show, found in the log-book which Mr. Olsen, in conjunction with the late Mr. Buckland, has sent out for the last three years. One fact may just be mentioned as communicated by them. In one particular spot in the North Sea they find fish more or less maimed or emaciated, and among them a very few splendid healthy ones. Now this is their idea: the locality is the hospital, the healthy fish are the nurses, and the flora found there a specific for their ailments, or an asylum from pursuit, in accordance with what is known of land animals. A very able description, regarding the depths of water and the nature of the bottom, followed, over twenty different kinds of soil being enumerated. Next, the author gave an account of about fifty different kinds of marketable fish, caught by the trawl, and a graphic history of this implement from its introduction to its present development. Previous to railways the trawling trade was of very little importance, but the great facility for the transport of fish has contributed much to its present magnitude. From open boats, of about ten tons, to modern smacks of from 80 to 100 tons, and costing from 700*l.* to 1,500*l.*, nay even some with refrigerators and screw trawlers, costing up to 4,000*l.*, is a great stride.

The fishing fleet of the United Kingdom numbers about 40,000 vessels, carrying about 150,000 men, besides boys. Particular statistics are given in the Fisherman's Almanac.

These brave fishermen of the North Sea, the author stated, would be of invaluable service for coast defence, and by his scheme could be organised and kept in a state of efficiency, even without cost to the State.

From the foregoing it will be seen that the author has a threefold object in view, viz., the feeding of the nation, assistance to science, and the defence of this country.

SATURDAY, AUGUST 26.

The following Papers were read:—

1. *On Some Influences affecting the Progress of our Shipping and Carrying Trade. By* Hyde Clarke, *F.S.S.*

Taking the English tonnage engaged in the foreign trade at 9,000,000 tons in 1850, and at 41,000,000 in 1880, he proceeded to consider what were the causes to which

the increase was due. These he referred to the general progress of the world, the throwing open to commerce of the Pacific regions of China, Japan, California, &c., the colonization of New Zealand and parts of Australia, and the discovery of gold in California and Australia. These events had nothing to do with free trade or fair trade, and it was essential to regard the real conditions for a right understanding of them and the avoidance of misleading authorities. Another influence in our favour had been the revolution by which timber and hemp, as constructive materials of shipping, had been replaced by iron and steel, the former being imported from abroad, and the new materials, with coal for working, being of home production. In these materials too we had an advantage over many countries. Sailing vessels had been displaced by steam. It was a matter of moment in the economic condition of the nation that home resources should be applied, and in the result this produced enormous advantages. Our duty was to study all means by which our national wealth can be augmented under the most favourable conditions.

2. *Our Sailors—for Defence and Commerce. At Home and Abroad.* *By* C. Pfoundes, *F.R.G.S.*

As the great maritime nation of the age, it is necessary that we be prepared for all emergencies, and fully able to protect our ships and our territories at home and abroad.

The separation between the seamen and officers of the navy and those of the mercantile marine is widening year by year, in consequence of the special technical training for all ranks in the navy. The naval reserve, merchant seamen, and volunteer naval brigades are not encouraged or supported. The national love of 'a sailor's life' is not fully developed and taken advantage of; and the merchant seaman is not rising in the social scale, but rather deteriorating physically and otherwise.

Recent essays and discussions point more to the details of the education, &c., of the naval officer. The 'seaman' is treated as a very minor matter; and the capacity of our colonies to furnish a large contingent of the very best material is altogether ignored by the modern navy men.

The thoroughly efficient, fully adequate, and economical provision of any requisite number of seamen appears most necessary, from a practical standpoint, as seen by one who has had personal experience amongst the classes that would give us the raw material.

History and statistics point out what should be copied and what avoided, whilst fully considering the change in the condition of politics, society, ships and guns. Although not so much a military as a maritime people, we have greatly encouraged our rifle volunteers, but completely ignored, if not actually discouraged, naval volunteers; certainly in no way has a taste for sea life been fostered amongst our youths, and the time is not far distant when this negligence will produce disastrous results. Second-rate powers are forming navies, that combined would prove dangerous enemies, especially if allied to any 'great power' we might be at war with. Remote China, or Japan, or even a South American republic, might send to sea vessels that would cause us serious trouble, if not actually inflict great injury on our shipping or distant possessions.

In the mother country and the colonies there are thousands of men who follow a seafaring life, many men of means fond of boating and travelling, not a few men who have been 'seafarers' at one period of their life. There are numbers of pensioners, trained men capable of giving primary instruction; and there are tens of thousands of young men on the seaboard and inland, who would be glad to 'volunteer,' if only this 'wealth of material' were duly organised and received a fair meed of support and encouragement here at home and in our colonies.

MONDAY, AUGUST 28.

The following Report and Papers were read:—

1. *Report of the Committee for inquiring into the present Appropriation of Wages and other sources of income, and considering how far it is consonant with the economic progress of the United Kingdom.*—See Reports, p. 297.

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2. *The Abstract Theory of Rent. By* F. Y. Edgeworth.

The writer attempts to present the Ricardian theory as a first approximation, at once requiring and required by a more accurate statement.

Let a line, ox, represent by its parts the quantities of land of each quality. Let perpendiculars thereto represent amounts of labour and sacrifice expended upon land. On each unit rectangle of the plane, xy, erect a rectangular parallelopiped proportional to the corresponding amount of produce. Then the total produce may be conceived as gathered into a barn of a peculiar shape. The highest point is the rectangular corner, o. From this point the height of the straight walls, ox and oy, gradually diminishes down to a certain minimum height, i. The extremities of these straight walls are connected by an outer wall, in general curvilinear or stair-shaped, of the same minimum height. The figure is completed by a sloping roof. A level floor, of height i, separates off a loft containing the landlord's portion of the total produce. The rest of the building may be divided by another level floor into two storeys, containing the portions of the capitalist-farmers and labourers respectively.

Now, the total contents being unaltered, let the roof be raised. The height of the outer wall will be increased, the contents of the loft will be diminished. Again, the roof being prolonged, but not otherwise altered, let the total contents be increased. The height of the outer wall being diminished, the contents of the loft will be increased. Let both roofs be raised and total contents correspondingly increased, the contents of the loft will be increased. And so forth.

Of course these metaphorical statements are but grossly approximate. It is not possible to arrange lands as Nos. 1, 2, and 3, according to their productivity; for productivity, being a relation between produce and expenditure, may, for one land as compared with another, be greater or less according to the different amounts of expenditure considered. Accordingly, the yz curves of our roof are not necessarily parallel. One may start at a great height, and descend rapidly, another begin low, and decline gently. Thus greater expenditure need not correspond to greater rent. This holds not only as between different lands, but also the same land under different cultivations. If, owing to improved cultivation, the same total produce is raised with less expenditure, rents need not be lowered; even money-rents may be raised. Again, though the return to the last dose of capital will be just what the farmer could have obtained elsewhere by investment without trouble of management, yet the return to his whole farming capital will not be in the same proportion, but rather regulated by the condition that he cannot with advantage transfer himself and his capital to any other business.

These and other exceptions, suggested mostly by Ricardo himself and his disciples, are calculated rather to fulfil than destroy the Ricardian rule. The abstract theory is as it were a type-photograph of the diversified real forms. It is an approximation not only near to, but on the only way to, the full truth. Those who now sneer at the great discoverer, forget that without his general map they would never have found out the region of their petty explorations.

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3. *The Ricardo Theory of Rent. By* Alfred Milnes, *M.A., F.S.S.*

Various weak points may be observed in the Ricardo theory as generally stated and applied:—that great difficulty is experienced by skilled economists in maintaining their self-consistency with regard to it, as evidenced (*e.g.*) by certain

mistakes made by Nassau Senior—that it is isolated from the complex of social phenomena—that it does violence to the ordinary use of language, and thus excites distrust in the ordinary mind. This feeling is of importance, and justifies another attempt to restate the theory of rent, to which end the statements given hitherto must be classified. The Physiocrats may be omitted, as standing apart from our purpose, and a cyclic tendency in the teaching of some of our leading modern economists will enable the classification of 'post-physiocratic' rent theories to be on an historical *fundamentum divisionis*, and four periods will be yielded:—1. Adam Smith; 2. Anderson, West, Malthus, and Ricardo; 3. John Stuart Mill, whose statement may be taken as the completed Ricardian phase of the question; 4. Thorold Rogers and Bonamy Price. From the teaching of this fourth period as a starting-point, the journey is very short to what it is hoped may tend to a completion of rent-theory—rent explained by reference to the Law of Equal Inducement to all employments. This law has a simple diagrammatic representation. Sundry anomalous payments may thus be brought under rent.

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4. *On Artisan Education.*
By Professor SILVANUS P. THOMPSON, *B.A.*, *D.Sc.*

The author referred to his paper on 'Apprenticeship Schools in France,' read in this Section in 1879, as giving information and statistics on the manual elementary schools, the factory schools, and the apprenticeship schools of France, which the recent preliminary report of the Royal Commission on Technical Education has described. The author claimed that no single new fact had been brought out by the report of the Commissioners, beyond the information that by a recent law it had been decreed that the education in such schools, as in all primary schools in France, should be gratuitous, and that manual training was now added to thirty primary schools in Paris. Reference was made to these manual schools as constituting a very important extension of the Kindergarten system of teaching. The author advocated the introduction of manual training into primary schools; the making of primary education gratuitous; and the necessity of making the experiment of establishing such schools in the smaller towns as well as in larger centres of industry.

TUESDAY, AUGUST 29.

The following Papers were read:—

1. *Railways—a Plea for Unity of Administration.*
By EDWARD J. WATHERSTON.

The author stated that the British railway system had lately been considered by a Select Committee of the House of Commons, and already there was a demand for a new trial, on the ground that the verdict was against the evidence. Certain it was that the report of the Select Committee could not be accepted as a settlement of so important a question, so weak were the conclusions at which they had arrived. To science the nation was indebted for the principle of steam-propelled trains, and now to science they must look for the administration of those undertakings. He summarised the complaints of the public and the replies of the companies. The Committee simply recommended that chambers of commerce and of agriculture should have a *locus standi* before the Railway Commission; a uniform classification of goods; the recognition of terminal charges; additional powers to the Railway Commission; the abandonment of canal control by railway companies; and, lastly, the amalgamation of the railways of Ireland by direct Parliamentary action. Such recommendations, if acted upon, would only make confusion worse confounded. If unity of administration were desirable in the case of Ireland, it was still more desirable in the case of Great Britain. Looked at superficially, the number of 623,000,000 passengers carried in one year might seem large, but it was

really not so if the figures were properly analysed. The same argument applied to goods traffic. Two hundred and forty-five millions of tons was a high-sounding figure, but when analysed the amount was but small. Were the railways, as at present administered, fairly remunerative to the shareholders? The answer must be in the negative. The average dividend for the entire United Kingdom was only 4·29 per cent. Hundreds of undertakings paid no dividend at all. The prevailing system was not altogether without its advantage to a section of the travelling public. No country in the world could show trains performing the journey from London to Edinburgh, 401 miles, in less than ten hours. Certainly in no other country could one travel 108 miles in two hours and a quarter, as was the case daily on the Great Western between London and Bath. Another advantage, although it was difficult to perceive any real national benefit accruing from such waste of power, was to be found in the fact that every morning and evening the traveller for the North had a choice of three different half-empty trains, all magnificently equipped, starting about the same time, and running at the rate of about fifty miles an hour, from Euston, St. Pancras, and King's-cross. Competition, it was said, was good for trade and good for the public. But here one failed to see any beneficial result, inasmuch as the three companies had adopted the principle of 'unity of administration' as to the amount of their charges. In reality, not the shareholders, but the public, must in the end pay for wastefulness and improvidence in railway management; the loss must be recouped by placing 'the million' under contribution, taxing them in the shape of exorbitantly high fares. This was systematically done by all our railway companies. Foremost among the disadvantages must be reckoned the disastrous effect upon trade. At present our manufacturers are handicapped in competition with foreigners by the excessive rates for the inland carriage of goods, and by the cost of commercial travelling. We hear of rents badly paid, and of no rents at all—of farms even out of cultivation. And yet there may be food at one end of a line of railway wanting mouths, and mouths at the other end wanting food, and it does not pay to bring the one to the other. Eccentricities of charges are observable on all classes of produce. The application of the principle of unity of administration, with the consequent lowering of rates and fares, would tend to equalise the value of landed property all over the kingdom. With cheap transport, the price of all commodities —food in particular—would naturally sink enormously, in favour of the consumer, whereas its value to the producer would as assuredly rise. It is simply incalculable what the increase in value of landed property, removed from large centres of population, would be if railways were organised like the Post Office. Railways have doubled the value of many an estate, and they would quintuple it if they ceased to be matters of private speculation, and were managed in the interest of the nation. The advantages to the public include:—1. The possibility of a general lowering of charges both for goods and passengers. Millions who now do not travel for want of means, would then come to fill the trains. That it would pay to carry these millions is quite certain. 2. The suppression, as far as possible, of what are called 'accidents.' Mismanagement is the cause of nearly all of them. In the single year 1880, the number of persons killed on the railways of the United Kingdom was 1,135, while the wounded numbered 3,959. Of this total, 546 killed and 2,080 wounded were railway servants. 3. A greatly improved system of postal services. If all our railways were under unity of administration every station could easily be turned also into a post office, when every train could be accompanied by a travelling postal carriage for the sorting of letters as well as of parcels. The progress of internal trade and the movement of population thus originated would probably not be less than that produced by the introduction of the railways themselves, when superseding the old stage coaches. 4. The position of shareholders would be improved. It must be remembered that we are dealing with a business yielding a gross return of 66½ millions sterling; that the net divisible profits now amount to nearly 32 millions; that, under unity, large savings in administration would be possible; that an army of directors (who would clearly be entitled to compensation) would be dispensed with; that the cost of a clearing-house would be saved; that we should not be so foolish as to

maintain the impolitic tax upon railway travellers, now a charge of nearly three-quarters of a million upon working expenses; and that, upon nearly 182 millions of 'loans and debentures' an enormous saving in interest would be effected, seeing that a railway trust could borrow at 3 to 3½ per cent., instead of 4, 5, and 6, and even 7 per cent., as prevails under the present system. It would matter but little to proprietors whether income were derived from a 3 or 3½ per cent. 'consol' stock, or from a 16½ per cent. 'Taff Vale' stock, and if it were guaranteed, as shown by the late flutter among water shareholders, an enormous rise would take place in the money value of such income. Moreover, there are the proprietors of 46 millions of unremunerative capital to be considered. Nothing can be more clear than that these undertakings should be treated as bankrupt concerns, and sold for the benefit of creditors. They should be valued, and taken over by the 'Railway Trust' at their fair valuation. There should be one central government of all the lines, with the service so arranged as to meet the utmost public convenience. The end kept in view should be to assimilate on the same principle the transport of letters, of telegraph messages, of persons, and of merchandise.

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2. *Cottagers and Open Wastes in the District of the New Forest.* *By* G. E. Briscoe Eyre (a Verderor.)

The subject of 'Cottage stock-keeping in connection with commonable lands' is not peculiar to the district, but is probably more largely exemplified here than elsewhere in the South of England.

This subject does not lend itself readily to statistical treatment for various reasons. The cottagers are exceedingly reserved, and information is difficult to obtain; besides, few of them keep accounts, and the method pursued and its results vary somewhat with the seasons and depend greatly upon the individuality of the cottager, upon his resources and his circumstances. But, considering the high average of success attained, these very difficulties stimulate me to draw attention to the subject, in the hope that some experienced economist may write hereafter the chapter of which this paper is a first rough draft. For, so far as I can learn, the value of common rights to the exercisers and the method of their exercise is but imperfectly understood, and yet some economic counterpoise is sorely needed to the prejudice with which the 'commoner' is too often regarded. The cottager-commoner is termed contemptuously a 'squatter,' although in many cases his freehold, copyhold, or lifehold tenement may date from Saxon times, and although his common rights, often a relic of our Saxon liberties, may be as truly his property as the soil of the wastes whereby he largely lives is the property of the Crown or of the lord of the manor. Few landlords, land agents, or land stewards and the like, seem to regard a 'commoner' even with tolerance, and fewer still seem to have considered his value in the national economy. In particular, a just and intelligent consideration of such commoners has too often been lacking in past times amongst those who have deemed it their interest or their duty to promote the inclosure of commonable lands. For instance, it has been thought just that a common should be enclosed, provided the present owner of common rights could be induced to barter the right which would otherwise have benefited successive generations, for some small allotment in land. But as the exercisers of common rights well know, and the allottees have too often experienced, the parts of an extensive and varied waste when thus assigned in severalty, are never an equivalent to the small husbandman for his share in a joint enjoyment of the whole. And a valuable property (or legal estate) is thus partly sacrificed, or made easy to squander, and in practice is found to disappear very shortly by absorption into large estates.

In default of a sufficient perception of the lesser interests involved, open lands have often been enclosed only to prove a complete disappointment to the owner of the soil, and injurious to the true interests of the immediate neighbourhood and sometimes even of the country at large.

The present paper is an attempt to unfold those lesser interests, and in it I pro-

pose *first* to sketch in outline the region of the New Forest and the adjacent commonable wastes; and, *secondly*, to show how these wastes are used, and to give some specimens of the results.

A great forestal region, co-extensive with the peninsula or irregular parallelogram which narrows northwards from a base upon the Channel to the chalk downs of Wiltshire, forms the south-west section of the county of Southampton. It is bounded by the river Avon on the west, by the sea on the south, and on the east by the Southampton Water, and by the Hampshire or lower portion of the valley of the Test, as far as its northern boundary. The New Forest occupies the greater part of this area. Regarded as a whole, this region is an undulating heathy waste, sloping east and south-east from 'plains' of about 400–250 feet elevation above the sea, and having an axis generally parallel with the valley of the Avon. From this axis long level ridges radiate and finally descend, with a more or less rounded outline, into a broad expanse of flat 'heaths' which extends to the sea, averaging about 100 feet above sea-level. The surface of the region, a deposit of gravel upon the Barton clays, has been denuded until the water-bearing Bracklesham beds and hungry Bagshot sands are laid bare, and only gravel-capped ridges and isolated hills remain to attest its former character and gradual slope. The spurs of these ridges enclose basins of horse-shoe form or elongated, and varying in diameter, each comprising a series of convergent valleys hollowed out by the surface-water, and deepened and broadened at about the 100-feet contour by the outflow of the underground water. Thus the soil of the present surface varies from gravel to clays and sand, as the denudation has extended downwards.

The area of the highest and of the lowest lands being for the most part uncultivable, the cultivated or more or less wooded lands are found extended as promontories or islanded as hills between the gravelly heaths above or the sandy heaths below. A few low-lying bottoms owe an exceptional fertility to a kind of alluvial deposit from above, and contain the precious 'lawns;' and in particular, great morasses or lesser bogs fill the hollows of the sandy heaths, and are covered with coarse marshy vegetation. Accordingly, we find the majority of the ancient farms and demesne lands of the Forest or the adjacent manors situated in elevated localities between the 200 and 100 feet contours of the new Ordnance Map, while the upper and lower heaths surrounding these oases and the woodland between form the wastes, upon which the inhabitants from time immemorial have exercised their rights of turbary, pannage, and of pasture. Here and there, some brown hamlet on high ground, or a stray cottage with its little plot and orchard, nestling in some sheltered hollow or skirting the roadside, varies the uniformity of the heaths.

It is with the value of these wastes, at first sight so unpromising, that we are now concerned. Comparatively modern encroachments and inclosures excepted, they are what they were centuries ago while they were yet the favourite hunting-grounds of our kings, or were accumulating in the hands of the great religious houses. The kings discouraged all change in the interest of the royal beasts of the Forest—the wolf, the red and fallow deer, badgers, &c.; and abbots and abbesses rather encouraged than otherwise the small copyhold tenants, who paid a timely though insignificant rent in fat capons at Christmas.

It was probably due to the predominance of the Crown that the general movement towards inclosure, with its attendant hardships and disturbances, which culminated in the reign of Edward VI., was little felt in this region. This movement, which called forth the denunciation of Bishop Latimer and others, led in many other districts to the destruction of the very class of cottage farmers of whom I am about to speak. But that a new comer sometimes tried to 'make his profit' of the wastes appears from a decree of Elizabeth's reign, declaring and confirming the rights of eleven small copyholders (amongst other customs) to pasture their cattle upon the wastes of two manors adjacent to the New Forest. Their bill of complaint against William Pawlett, lord of the manors of Wigley and of Cadnam and Winsor, recites graphically that 'the said complaynants were poore coppieholders of the Manor of Cadnam and Winsor, and their whole estates and livynge depended upon the same, soo that yf they should be abrydged of there anncyent customes it would be their utter undoinge.'

In the New Forest, a hundred years later, a limited power was granted to the Crown, by Act of Parliament, to enclose a portion of the wastes for the growth of ship-timber; but the Act jealously protected the commoners whose petitions against the Bill describe the Forest as immemorially 'a great nursery for breeding cattle,' and speak of 'many thousands' as 'dependent' on their rights of 'pasture, turbary, and pannage' in it. The Act provided that the land to be enclosed should be that only which could be 'best spared from the commons and highways,' and provided further, that the inclosures should be again thrown open to pasture so soon as the trees should be past injury by cattle.

Thus did the Court of Chancery and Parliament protect the poor in 1591 and 1698 in the Forest and the manors. The lord had not in those days, as practically he has had in the nineteenth century, for his one-sixteenth of ownership fifteen-sixteenths of the law; it was not necessary, when the value of rights of common were generally understood, to spend thousands of pounds sterling in appealing to the Court of Chancery for protection, nor years in agitation, and weeks in committee-rooms to get a hearing from Parliament. And so, injurious inclosure was arrested until the beginning of the nineteenth century. As only a small fraction of the surface was worth cultivating, and as crafty attempts to sow the wastes with timber for the benefit of the lord failed, because the Scotch fir, the most modern engine of such encroachments, was either unknown or not procurable, these wastes remained until within living memory *in statu quo*. The bogs, the brook-side, and the swampy 'lawns,' continued to provide the cattle of the commoners with pasture; the heaths furnished turf for fuel and ashes for their land, and the shaggy untended woods yielded beech-mast and acorns for their pigs, and timber for fuel and for the repairs of house, hedge, and implement.

Before passing on to show the use and value of the several rights of common, attention should perhaps be drawn to some elements which make this region a type of what commonable pasture-land should be. It combines an extended range with considerable variety of soil and of water-supply, and with, perhaps, every variety of shelter and exposure. Any deficiency in one section, especially in running water, is supplied by sufficiency or excess in another; constant change of ground (essential to success in stock-management) is ensured, being caused by the seasons, by the weather, and by the instinct of the animals, which, further, in seeking food, and a suitable soil under foot, find healthy exercise. The importance of an extended range is especially seen from the rarity of those exposed ponds, or wet, or even dry, spots called 'shades,' indispensable in summer, where a local draught in a treeless expanse relieves the animals of the flies. Driven from the woods and sheltered grounds, the animals then travel for miles 'to shade,' as the term is. Lastly, the 'turn out' in winter and spring has a real value, due partly to the mildness of the winters, snow being rare and never lying long—partly to the early feed of the swamps and bogs, at its best when the meadows are parched with drought—and partly to the accessibility of healthy ground when the meadows lie cold and swampy with the winter rains.

The foregoing description roughly indicates the peculiar advantages secured to this section of the county by the preservation of these open spaces. Let us now see how these advantages operate, and with what results. To speak generally, the region is characterised by a moderate but widespread prosperity, even in these hard times, and by a low percentage of pauperism; indeed, the prosperity of the lower strata of the agricultural population is prominent, especially that of small tenant-farmers and of the cottagers, and this can be distinctly traced to the judicious exercise of common rights. For the larger the farm, the less is the use made of the wastes. The land of the farms is of better quality, and the proportion of meadow is probably sufficient; the improved breeds of stock are too delicate to turn out upon the wastes, the tenant's capital is in most cases fully employed upon the farm, and his attention absorbed in an increasingly elaborate business. But the wastes are the cottager's farm; they are the source of his livelihood, or of his comforts, and of his capital. So he makes it his business to acquire the proper stock, and to work the commons to the best advantage. For such reasons, and because the simplicity of the cottager's life and business enables the effect of com-

mon rights to be traced with some accuracy and definiteness, the purview of this paper will be limited to this class.

The chief rights comprise common of turbary and (in the Forest) of fuel wood—appurtenant to the ancient houses, and common of pannage and of pasture—appurtenant to the land. There are other rights, viz., of taking marl (for manure), gravel, and sand; but the very valuable immemorial custom in the Forest of taking fern for litter was lost in 1854, partly through mismanagement, partly through the hostility of the representatives of the Crown. The right of cutting litter has been recently disputed by the Grantee of the Crown, Earl Delawarr, in Ashdown Forest, in Sussex; and the decision of the present Lord Coleridge and his two fellow Commissioners in 1854 against the commoners of the New Forest was alleged, but, notwithstanding, the right was upheld by the Courts after extensive litigation. In the New Forest, the fern is sold by the Office of Woods, but under conditions generally considered to be prohibitive; it is bought chiefly from necessity. Now, the cottagers buy leaves, the sedge-grass of the woods, &c., for litter, straw being scarce and expensive, though none of these make-shifts at all make up for the loss of the fern.

The right of turbary sometimes, *i.e.* in the manors, includes peat; the so-called 'turf' consists of disks of heather with the roots and adhering *humus*, pared horizontally from the gravelly and pastureless soils; it is burned on the hearth with a little wood, and makes a slow and economical fire. The ashes are much valued for the garden and farm. A turf-right averages 4,000 turves per house, and, being eked out with a few faggots or a little stump-wood, formerly kept a family in fuel through the winter. Nowadays the use of coal is on the increase. The value of the right is roughly reckoned at 10*s.* to 1*l.* a year.

The right of fuel-wood from the Forest averages a load to a cottage, and farms sometimes have a good deal more. These wood-rights, being costly to the Office of Woods, were keenly contested in 1854. Their value depends largely upon the distance from home at which the wood is assigned.

The right of pannage varies in value with the season, and with the commoner's power to take advantage of a good mast-time. The cottager who has saved a few pounds, observing the promise of beech-mast and acorns, buys in early and cheap as many pigs as he can hope to keep until September 25, or he buys a good-sized pig or two just before that date. He then turns them out on payment of 4*d.* for a hog and 2*d.* for a pig, and they return bettered to the value of about 10*s.* to 20*s.* a-head, and fit for immediate sale. In a good season 5*l.* thus laid out may be doubled in three months; but on the average of seasons a clear profit of 10*s.* per pig accrues on a number of pigs of all sizes. Perhaps the cottager's pig benefits most by a good mast, for the children collect large quantities of acorns along the roads and from the manorial lands, and after the pig has been taken in these are given to him with other food, and thus the mast can be made in all to save 2*l.* in food. The acorns are the better for a little keeping. Some cottagers adopt this method as soon as the mast begins to run short. At present the cheapness of food in proportion to the price of pig meat increases the profit of keeping pigs. Cottagers have been known to make 20*l.* a year by their pigs.

But it is the right of pasture which is of paramount importance. It gives a wide scope to enterprise, skill, and thrift; and while the expenses out of pocket are small, a modest capital can be accumulated (either by hard work and rigid economy in early life, or by the co-operation of a helpful family in later life), and a high rate of interest be obtained legitimately. An admirable investment is always ready to hand, and sometimes a family owes its first start to a windfall applied to stock-keeping on the wastes. From this right the most widespread benefit arises. The aged and the widow may make a bare livelihood and preserve their honourable aversion to parish relief; the shrewd and careful labourer may become gradually independent of work, and may even raise himself into the ranks of the tenant-farmers. There are labourers of these districts who are better off, all things considered, than many a skilled artisan earning full wages in London. Indeed, many a young man before leaving home has a colt or mare running on the open wastes, or possibly even two mares, before he is of age. As forest mares often breed yearly,

and yearlings fetch from 4*l.* 10*s.* to 6*l.* at the August fairs, and as pony stock can be wintered on the farms at from 1*s.* 6*d.* to 1*s.* a week, and 6*d.* for suckers, the ownership is both cheap and profitable. The care of a troop of five costs little more than the care of a single animal, and such a troop with average good luck brings in 20*l.* a year. Ponies are not wintered nor cared for unless they begin to stray and leave the Forest. And now that the *winter-heyning* is practically abolished, ponies begin to stay out longer. The cost of wintering is thus reduced by 10*s.* to 4*s.* per head. The ponies are habituated to some locality, and are left to themselves, being driven in only for marking by the agister, or when wanted for sale, so that they cost the owners nothing but the marking fees of 1*s.* 6*d.* a head per annum. The fillies are usually left at large; they run with the mares, and in their fourth year breed a good colt. Brood mares are much valued, and rarely sold; a very good one will fetch 15*l.* Heifers are less costly to buy, say 2*l.* to 4*l.*, and are nearly as self-maintaining as pony stock, until they have their first calf; but they need better pasture, and they cost about 1*s.* per week more if wintered. In the spring, they may be sold with calf at side for 10*l.* to 14*l.* each. But the cottager's ambition is to own a cow. In one case, quoted below, the calf was acquired as a weanling seven days old, costing 10*s.*, and was paid for out of its own milk two and a half years afterwards. In another, a heifer was bought for about 2*l.*, and paid for from its own butter a year or two after it came to maturity. No trouble, shift, or economy is spared—first to obtain, and then to rear the future cow. Nothing is wasted, and even the furze-tops are gathered in winter, and cut up with the other food. The result is that almost every cottager owns some animal—at least a forest mare or a heifer, if not both a cow and a pig, each of which makes the other more profitable.

It is estimated by our cottagers and small farmers that, if there were no wastes, a minimum of 3 acres of our forest meadows would be required to keep a single cow, *i.e.* an acre for hay and 2 acres for the usual little crops of mangel, &c., and to be used for pasture alternately. The rent of such a 3-acre lot would not be less than 4*l.*, and might be considerably more. But with the use of the wastes, the usual house-plot of 2 or 3 roods, if a good cow common adjoin, will support a single cow, except in a winter of exceptional severity. The cow lives by the common from May to November, while two crops of hay are secured from the heavily manured orchard, and a good after-grass is growing; but everyone who can afford to do so will give the cow a little something nightly. An expenditure of 2*s.* to 2*s.* 6*d.* per week in winter on hay, swede-turnips, and pollard, and on the materials for a mash (to the amount of about 50*s.* to 3*l.*) will increase the average weekly produce of butter throughout the year by one-half, say, from 3 lbs. to 5 lbs. per week. This butter is sold at the gate for 1*s.* 2*d.* a lb. on the average. Cases occur where a small capital of about 10*l.* will enable a second cow to be kept on the house-plot and common by the purchase of additional food. The calf will be sold at six weeks old for about 10*s.* profit, and all the skim milk will then go to fatten the pig. Each pig bought, fatted, and sold at about four-score weight may produce in six or eight weeks a profit of 1*s.* per week up to 10*s.*, and with high feeding will produce a little more; but the value of the pig has lain, until lately, rather in the fact that he helps to turn everything to use and provides a valuable manure. Of course the number bought and sold annually will depend on circumstances, capital, and on the mast-time. Widows and such-like owners of a single cow often kill and salt a pig, the cost of which may be cheapened by about a third if there is a good mast. The profits of a house-plot and single cow, with its complement of pigs, may be estimated at from 4*s.* to 10*s.* per week, according to the means and opportunities of the cottager, and, speaking roughly, it is probable that our labourers not unfrequently earn the double of their weekly wages by such stock-keeping as the foregoing. If an acre or 1½ acre of meadow can be added, there will probably be two cows and a sow, and two or three fatting pigs on the premises. As before, the cows are 'turned out' while the hay is growing, and will maintain themselves entirely on the common from May until November. The wife's spare time suffices for the management of two cows and the corresponding number of pigs; meanwhile the husband is earning regular wages abroad,

and easily obtains an occasional day to get in the all-important hay crops of his orchard and mead, or to empty the rude outbuilding and spread its contents upon his little holding. With the third cow, expenses out of pocket begin. Few wives can now manage without a boy to help, and the husband, obliged to be more and more at home, must substitute task work for day work. Or he will set up a pony and cart and begin dealing—first, as a higgler, or dealer in butter, eggs, poultry, and garden produce, which he buys of the cottager and sells in the market town—and later, as a general dealer on a larger scale. He employs his spare time in carting turf, fuel, wood, chalk, &c., for his neighbours at 5*s.* a ton. But the middleman's business is not without its drawbacks, and the careful housewife regards with some anxiety the social habits and long absences which it involves.

The next and most important stage is reached when the cottager can rent about five acres of meadow and stock it with three or four cows, a couple of sows, and can rear a heifer and sell two calves, and fat 10 to 12 pigs yearly. An advance beyond this point will involve hired labour, unless the children are well-grown and helpful. Here the cottager often hesitates, for the thrifty stop short of hiring labour. Probably he has reached the limit of his out-buildings and of his power to winter stock. But if he advance, the next stage is a 'little place' of 8 to 12 acres, and the man having then become practically a tenant-farmer, passes out of the limits of this paper.

By the foregoing details the use and value of these wastes and of the rights over them will have been indicated generally. We may now try to trace the financial results. Precise financial results will hardly be expected, for the two livelihoods of the cottager, viz., the ordinary and that arising out of his common rights, must intermingle inextricably. But by isolating the stock-keeping and then separating off the actual monetary transactions in that branch, results of approximate accuracy may be obtained, and the value of the whole be inferred from the profits of a part. The following table, the result of much consultation with competent cottage stock-keepers, shows the approximate profits on each head of stock; and anyone desirous of pursuing the subject further will find, the author believes, that by applying this as a standard to any given head of cottager's stock for a given time he will not overrate the profits actually realizable. The amounts are small in themselves, but large when compared with a labourer's weekly wage. They show a large percentage on the outlay, but the labour and superintendence are not charged; the stock-keeping is regarded as added to the cottager's living.

ESTIMATED (*out of pocket*) COSTS AND PROFITS OF COTTAGERS' STOCK.

——	Cost to Purchase	Cost to Rear	Average Profit
PONY-STOCK:— Sucker (3 months)	1*l.* to 2*l.*	(If wintered) 6*s.*	(See next entry)
	£ *s.* *d.*		
Yearling (15 months)	4 0 0 to 6 0 0	(If wintered) 9*s.*	Sale price (unless wintered)
2–3-year-old . .	6 0 0 to 8 0 0	(If wintered) 9*s.*	Sale price (unless wintered)
Brood mare (4 years and upwards) .	8 0 0 to 12 0 0	(If wintered) 9*s.*	Two yearlings every three years
COW-KIND:— Calf, weanling (7 days) . . .	0 15 0 to 0 18 0	(If wintered) 30*s.*	(See next entry)
Heifer (6 months) .	2 0 0	Wintering—say 50*s.* a winter, if no land	(See next entries)
Heifer, yearling .	4 0 0 to 7 0 0	Wintering—say 50*s.* a winter, if no land	—

——	Cost to Purchase	Cost to Rear	Average Profit
Heifer, with calf at side . . .	10 0 0 to 14 0 0	(See foregoing entries)	3*l*. 10*s*. to 7*l*. 10*s*. (if home-bred)
Heifer's bull calf (7 days) . .	0 10 0	To fat, for sale in six weeks, 40*s*.	5*s*. to 10*s*.
COW:— (according to age) .	9 0 0 to 15 0 0	Wintering—say 3*s*. a week, if no land	12*l*. to 18*l*. per annum (with calf sold)
Cow's bull calf .	—	(See *Heifer*)	(See *Heifer*)
SWINE:— Sow (young) . .	0 15 0 to 1 0 0	1*s*. per week (exclusive of skim-milk, garden-refuse, &c.)	—
Sow, full grown .	2 10 0 to 5 0 0	1*s*. per week (exclusive of skim-milk, garden-refuse, &c.)	—
Litter of 9 pigs (at 6 weeks) . .	0 10 0 to 0 14 0 each	30*s*.	3*l*. to 4*l*. 15*s*.
A pig (to fat) . .	1 5 0 to 1 10 0	Porker (8–10 weeks, *i.e.* to 5 score weight) 3*s*. 6*d*. per week	The manure (and 10*s*.)
A pig (to fat). .	1 5 0 to 1 10 0	Bacon (9–12 months, *i.e.* to 12 score) 2*s*. a week for 6 months and 4*s*. 6*d*. a week for 3 months (less saving by mast-time)	The manure, and value (say 6*l*. if bought at 6 weeks and home-bred)
A pig (to fat). .	2 10 0 to 3 0 0	Bacon (9–12 months, *i.e.* to 12 score) 2*s*. a week for 6 months and 4*s*. 6*d*. a week for 3 months (less saving by mast-time)	The manure, and value (say 6*l*. if bought at 6 weeks and home-bred)
A pig (to fat) if for mast-time .	1 5 0 to 1 10 0	Nil	10*s*. per pig (on a quantity of all sizes) to 2*l*. each on one or a few

NOTE.—In the Forest the Agistment Fees or Headmoney under the Acts of 1877 and 1879 are:—

	Marking: Pony-stock	Marking: Cow-kind	Pannage
For a Registered Commoner . . / „ Licensee (Act of 1879) . .	1*s*. 6*d*.	1*s*. 6*d*.	4*d*.
		Milch cows and under 1 year, 6*d*.	

But, fortunately, it is possible to give the actual profits of a twelvemonth's stock-keeping on a 'little place' of six acres, with cottage, cowpen, and pigstye. The stock kept was three cows, one heifer, and one weanling calf; twenty-four pigs also were bought and sold in the year. The labour-bill included hay-making, emptying the pens and styes, and all rough work, the cottager being a middle-aged bachelor, with considerable savings. The profits on the cow-kind—made by sale of butter, new milk at 4*d*. per quart, skim-milk (to oblige) at 1*d*. a

quart—amounted to 39*l.* 18*s.* 6*d.* The profits on the pigs—fatted largely on bought food and sold at about five score weights—amounted to 21*l.* 14*s.* 9*d.*

The year's net profits therefore amounted to 61*l.* 13*s.* 3*d.* The *maximum* profit made by this cottager in any year was 77*l.* 5*s.* 11*d.*, and the *minimum* 59*l.*, say 10*l.* an acre.

There is reason to believe that a few other cottagers, without this man's special experience, may be as good managers, but his experience in keeping accounts is unusual, and these may be regarded as trustworthy.

The general results may be summed up briefly. The cottager lives the life of a labourer, but his earnings are those of a farm of about thrice the size, and twice the rent of his little holding. The cow provides a weekly, the pig a quarterly, and the heifer or pony an annual income, which can be reinvested in the business, which the cottager thoroughly understands, at a good or even very high interest. The effect on character in forming habits of industry and thrift is obvious, and experience shows that it is generally permanent. Financially, also, the result seems to be permanent, notwithstanding a stroke of ill luck or a bad season or two. Bankruptcy in this class is, as far as I can learn, unknown. Neither does the cottager fall a prey to the money-lender. Lately, I was examining the court rolls of a manor adjoining the Forest, and, between 1700 and 1825, I observed that the old copyhold families were slowly dispossessed by the money-lender (often the brewer of the market town) with melancholy sureness and uniformity, and I observed also that in their turn, the new names which came in as mortgagees went out as mortgagors.

It remains to deal with two points mentioned at the outset of this paper, viz., the opportunity which cottage-farming in connection with common rights opens to the labourer to better his position, and the comparative absence of pauperism where the system has full scope.

Regret is often expressed, on various grounds, at the disappearance of the British yeoman. But in the region under consideration he survives, and the cottage-commoner is the source whence this ancient link between the labourer and the gentleman is maintained.

The way in which the stepping-stones are provided may be illustrated by examples. [The author quoted instances within his own knowledge, in which labourers and others have risen into the class of tenant-farmers and small proprietors.] But perhaps the most intelligible and indisputable proof of the value of these open spaces and common rights is the comparative absence of pauperism in the region.

It has been shown that not only can the commoners make a reasonable provision against illness and old age, but that the modest sum which might not outlast the long and hale old age of this healthy region, if applied to daily necessities, is either saved or invested in stock-keeping, and so made to produce a fairly steady and sufficient pittance. Old people of reasonably active habits, or with a little help if infirm, can keep at least a single cow, and profiting by the experience of a lifetime may earn more than the parish could allow in outdoor relief. The statistics of pauperism show that these 'chances' are used to the full. A typical parish may be taken from the nine parishes of the New Forest Union which embraces the eastern and larger half of the district under review. The half-yearly return (to Michaelmas 1881) for Bramshaw, a typical parish as to size and position, containing 823 souls, and surrounded by the wastes of the Forest and wastes of the manors, shows that it has only three in-door and eleven out-door paupers, and an expenditure of 46*l.* 8*s.* 6¼*d.*, but there is an exceptional expenditure of about one-fourth (8*l.* 3*s.* 7*d.*) due to the bankruptcy and death of a considerable tenant-farmer with a large family, so that we may fairly reckon the out-door relief at 38*l.* 5*s.*, *i.e.* at 76*l.* 10*s.* a year. For the Wiltshire section, there are no indoor paupers, and only three outdoor; for the Hampshire section, in which a few low-class and modern cottages have not the ordinary garden and orchard, there are three in-door and eight outdoor paupers. The published details show that this relief is given to cases of old age with infirmity, and to widows with families. But, without making any deduction, the amount is about 9 per cent. on the population—

and less than $\frac{3}{4}$ per cent. on the rateable value, and 13*d.* per acre of land other than wastes.

And if proof be required that this result is largely due to the prudent exercise of common rights, the evidence of one of the relieving officers of the Union, given before a Committee of the House of Lords in 1875, may be alleged to show that the inclosure of common lands within the Forest or in the adjacent manors, affected immediately the local prosperity of the population, and was especially felt by the neighbouring cottagers who owned cows. The tenor of his evidence can be borne out by other, and amounts to this, that those who kept a single cow previous to an inclosure could after it no longer keep any, and those who had kept two could only keep one. The further fact that the effect was rather seen in diminished livelihoods and comfort than in actual admissions to the workhouse, is an important testimony to the extent of the advantages conferred by these open wastes.

In conclusion, if I have at all succeeded in making out the case propounded at the outset, I would, with your permission, look a little into the future and submit one further point, appealing to you, not so much as lovers of justice, but as practical economists.

The fact will have struck many of you in visiting our district that the Scotch fir is rapidly overgrowing our waste lands. You are aware that the self-sown natural timber is the property of the lord of the soil, but will not perhaps be aware how fatal this fir is to pasture of any kind, or to what an extent the self-sowing of the Scotch fir is a recognised engine of legal encroachment. But if such commoners and common rights as I have endeavoured to describe are worth maintaining, should this method of abolishing both, literally by a side wind, be permitted to continue?

I once saw, when in the company of two learned members of the legal profession, many cartloads of fir-cones lying outspread on waste ground of the New Forest, to 'self sow' it with fir. No fir-trees grew within a mile in any direction. It is also notorious that old trees, long since fit for cutting, in the edges of plantations, are seeding wastes far and wide, with or without the knowledge of the owner of the trees. To what extent is this practice reconcileable with the fundamental law of property, viz., that a man may not use his property to the injury of the property of another?

3. *On Decimal Coinage and Measures in America.* *By* R. de Tracy Gould.

The author advocated the introduction of the system of metric measurements and decimal money, and gave an epitome of the history of their introduction into the United States of America.

4. *On a proposed International Congress to diminish the Casualties at Sea.* *By* Don Arturo de Marcoartu.

It is said that the British Commercial Marine is worth 230 millions sterling; that every year are lost 100 British ships and 1,600 lives. The author would not exaggerate if he said that all the marine at large lost one ship and ten lives per day.

The number of lives saved either by the life-boats of the Royal National Life-boat Institution of this country, or by special exertions, for which it has granted rewards since its formation, is 29,050. In 1881 they saved 1,121 lives.

It has been stated for a new charitable 'Society for the formation of Increased Places of Safety on our coasts' that the primitive one, with an income of 40,000*l.*, only saved 500 persons a-year. If those figures are correct, that means that the saving of each life cost 80*l.*

However, all English and foreign charitable associations are devoted to save the lives of the wrecked, not to avoid or to diminish the collisions, the fires, and all the causes of the wrecks.

The British Act of 1854, the Acts of Parliament relating to boats and buoys, are now quite powerless, and of little use for saving life in wrecks. The number and conditions of the boats, and the number and conditions of the buoys, can only offer saving to one fraction of the human life shipped. What will be the sure fate of the majority of the travellers in each one of two modern iron steamers, with 400 or 500 lives, with boats only for 100 hands, coming in collision in the ocean at the speed of 14 or more miles per hour? Remember the recent collision at full speed of the *Douro* and *Yurac Bat* on a bright night. Neither the National and Mercantile Marine nor the Government has done what is required to avoid those sorrowful casualties. We must demand of science to fight against those enormous losses of life and wealth by promoting a special International Congress to investigate the means to diminish the casualties at sea. This congress will ask for the co-operation of meteorology, telegraphy, the building industry, and navigation. Meteorology can improve, extend, and make more perfect the system of storm-warning and meteorological reports. It is now an undoubted fact that the warnings of storms from the Meteorological Offices in Europe and in America have diminished the casualties at sea.

From the 1st of this month until August 31, next year, in pursuance of a circular from the British Meteorological Office, the masters of ships crossing the ocean will be taking daily observations, to be sent to the London Meteorological Office, to know twice daily the state of the sea and of the atmosphere. These observations will give important knowledge to establish more perfect warnings, and in any case will deserve great interest to prepare more valuable inquiries.

It is most important to improve oceanic telegraphy. At the present time the ships alone keep the almost primitive system of flag and rocket signals; and now it is possible to introduce one of electrical, acoustical, and optical telegraphy to communicate between the ships themselves, and with the coasts. The effect of this more perfect maritime telegraphy will be to avoid, or, at least, to diminish collisions; and the ships will have the knowledge of the state of the seas, and of the atmosphere wherever they go or call by the telegrams sent to and from the coast, or from the ships which proceed from those seas. The ships with that more perfect telegraphic system will be able to demand more easily saving appliances from the coast or from the other ships.

In regard to the building industry it has been remarked that the modern iron steamers offer smaller floating sections, and smaller floating bulk, than the old wooden ships. The painful history of the last wreck gave an illustration of how rapidly the iron steamers have been sunk. The ever-increasing speed of modern navigation means certainly increased and more frequent danger and more tremendous shocks, that is to say, increased loss of life and property. Therefore great reform is needed in the building system, in order to diminish the number of collisions and all casualties, and to supply at the same time more rapid and powerful implements to save life and cargo.

Finally, as regards navigation, the 'track' or road at sea must be fixed by police rules, as on the railway it is necessary to make a compulsory different track for each different direction. This principle is observed for the translantic steamers of the Cunard Line to avoid collisions, either with icebergs or with vessels from an opposite direction. Specially, in the most frequented passages, as are for instance the crossing points of the lines from England to Gibraltar, and from Europe to America, must be established police rules of navigation by international conventions.

In view of studying the practical means to diminish the maritime casualties, an International Congress is intended to be held in Spain. The author desired that the British Association should make some suggestions, so as to bring to a good result the proposed Congress.

SECTION G.—MECHANICAL SCIENCE.

PRESIDENT OF THE SECTION—JOHN FOWLER, C.E., F.G.S.

THURSDAY, AUGUST 24.

The PRESIDENT delivered the following Address:—

OF all the important sections of the British Association the one over which I have now the honour of presiding is, you will all, I think, admit, at once the most practical and the most characteristic of the age. In future times the present age will be remembered chiefly for the vast strides which have been made in the advancement of Mechanical Science. Other days have produced as great mathematicians, chemists, physicists, warriors, and poets, but no other age has made such demands upon the professors of mechanical science, or has given birth to so many men of eminence in that department of knowledge. Though a member of the profession myself, I may venture before my present audience to claim that the civil engineer is essentially a product and a type of the latest development of the present century. Telford has admirably defined the profession of a civil engineer as 'being the art of directing the great sources of power in nature for the use and convenience of man, as the means of production and of traffic in states both for external and internal trade, as applied in the construction of roads, bridges, aqueducts, canals, river navigation and docks, for internal intercourse and exchange, and in the construction of ports, harbours, moles, breakwaters, and lighthouses, and in the art of navigation by artificial power for the purposes of commerce, and in the construction and adaptation of machinery, and in the drainage of cities and towns.' This definition, written more than half a century ago, is wide enough to include all branches of engineering of the present day, although amongst those specifically mentioned the departments presided over by the railway engineer, the locomotive superintendent, and the electrician will be looked for in vain. As Telford was beyond all question the most widely experienced and far-seeing engineer of his time, this little omission well illustrates and justifies my statement that the typical civil engineer of the day is a late product of the present century; for even Telford never foresaw the vast changes which railways, steam, and electricity would evolve in the course of a few years.

My predecessors in this chair have on several occasions stated their conviction that it was better for the author of an address to confine his attention to the particular department of engineering in which he had special knowledge, than to wander over the whole field of mechanical science. A well-informed man has been defined to be a man who knows a little about *everything* and all about *something*. If you give me credit for being a well-informed engineer, I will endeavour to justify your good opinion by showing, whilst presiding at these meetings, that I know a little about steam-navigation, and machinery generally; a little about iron and steel, and other manufactures, and I trust a good deal about the construction of railways, canals, docks, harbours, and other works of that class.

There have undoubtedly been published during the last fifty years many works of mark and merit, but the work which above all others would, I think, have astonished and perplexed our ancestors, is the little one known to all the civilised world as 'Bradshaw.' This indispensable handbook of the nineteenth century testifies that the face of the country is dotted over literally with thousands of railway stations; that between many of these stations trains run at two-minute intervals, whilst the distance between others is traversed at a mean speed of nearly 60 miles an hour. The public are often justly indignant at the want of punctuality on some railways, but they should blame the management and not the engineers, for the daily conduct of the heavy traffic between England and Scotland shows, that notwithstanding

the constantly varying condition of wind and weather in this climate, a run of 400 miles can, on a properly laid-out railway, and with suitably designed rolling-stock, be accomplished with certainty to the minute, if the management is not at fault. On the Great Northern Railway, for instance, of which I am consulting engineer, the 400 miles between London and Edinburgh is traversed in nine hours, or deducting the half-hour allowed at York for dining, at the mean rate of no less than 47 miles per hour including stoppages. A few months ago the Duke of Edinburgh was taken on the same line of railway from Leeds to London, a distance of 186¾ miles, in exactly three hours, or at a mean rate, including a stop at Grantham, or over 62 miles an hour. I know of no railway in the world where this performance has been eclipsed, and it will be perhaps both instructive and amusing to contrast with it the performance of the engines at the opening ceremony of the Liverpool and Manchester Railway, on September 15, 1830. A newspaper correspondent of the time, after describing many eventful incidents of his journey, proceeds as follows:—'The twenty-four vehicles left behind were now formed into one continuous line, with the three remaining engines at their head; and at twenty minutes past five o'clock we set out on our return to Liverpool. The engines not having the power, however, to drag along the double load that had devolved upon them at a faster rate than from 5 to 10 miles an hour (once or twice only, and that but for a few minutes, did it reach the rate of 12 miles an hour), it was past eight o'clock before we reached Parkside. Proceeding onwards, we were met on the Kenyon Embankment by two of the missing engines, which were immediately attached to the three which had drawn us from Manchester. We went still slower than before, stopping continually to take in water (query to take breath), and creeping along at a snail's pace till we reached Sutton inclined plane, to get up which the greater part of the company were under the necessity of alighting and making use of their own legs. On reaching the top of the plane we once more took our seats, and at ten o'clock we found ourselves again at the company's station in Crown Street, having accomplished the distance of 33 miles in four hours and forty minutes.'

The incident of the passengers descending from a train headed by five engines to walk up an insignificant incline is, I think, worthy of being recalled to the remembrance of the travelling public who are accustomed to see without astonishment a single engine rushing along with a train of a dozen heavy carriages at as high a speed as if it were running alone. We must do our immediate forefathers, however, the justice to remember that even they effected some considerable improvements in the speed of locomotion. For example, in 1763 the only public conveyance for passengers between London and Edinburgh was a single coach, which completed its journey in fourteen days, or at the average rate of 1¼ mile per hour. Strange as it may appear, there are at the present time many large fertile districts in Hungary where, owing to the absence both of road and water communications, a higher rate of speed cannot be attained in a journey of several days' duration.

An essential condition of the attainment of high speed on the railway is that the stopping places be few and far between. The Great Northern express previously referred to makes its first halt at Grantham, a distance of 105 miles from London, and consequently but little power and time are lost in accelerating and retarding the speed of the train. In the instance of the Metropolitan Railway, on the other hand, the stations average but half a mile apart, and although the engines are as powerful as those on the Great Northern Railway, whilst the trains are far lighter, the average speed attainable is only some twelve miles an hour. No sooner has a train acquired a reasonable speed than the brakes have to be sharply applied to pull it up again. As a result of experiment and calculation, I have found that 60 per cent. of the whole power exerted by the engine is absorbed by the brakes. In other words, with a consumption of 30 lbs. of coal per train mile, no less than 18 lbs. are expended in grinding away the brake-blocks, and only the remaining 12 lbs. in doing the useful work of overcoming frictional and atmospheric resistance.

Comparatively high speed and economy of working might be attained on a railway with stations at half-mile intervals if it were possible to arrange the gradients

so that each station should be on the summit of a hill. An ideal railway would have gradients of about 1 in 20 falling each way from the stations with a piece of horizontal connecting them. With such gradients gravity alone would give an accelerating velocity to the departing train at the rate of one mile per hour for every second; that is to say, in half a minute the train would have acquired a velocity of thirty miles an hour, whilst the speed of the approaching train would be correspondingly retarded without the grinding away of brake-blocks. Could such an undulating railway be carried out, the consumption of fuel would probably not exceed one-half of that on a dead level railway, whilst the mean speed would be one-half greater. Although the required conditions are seldom attainable in practice, the broad principles should be kept in view by every engineer when laying out a railway with numerous stopping-places.

Nearly thirty years ago, when projecting the present system of underground railways in the metropolis, I foresaw the inconveniences which would necessarily result from the use of an ordinary locomotive, emitting gases in an imperfectly ventilated tunnel, and proposed to guard against them by using a special form of locomotive. When before the Parliamentary Committee in 1854, I stated that I should dispense with firing altogether, and obtain the supply of steam necessary for the performance of the single trip between Paddington and the City from a plain cylindrical egg-ended boiler, which was to be charged at each end of the line with water and steam at a high pressure. In an experimental boiler constructed for me, the loss of pressure from radiation proved to be only 30 lbs. per square inch in five hours, so that practically all the power stored up would be available for useful work. I also found by experiment that an ordinary locomotive with the fire 'dropped' would run the whole length of my railway with a train of the required weight. Owing to a variety of circumstances, however, this hot-water locomotive was not introduced on the Metropolitan Railway, though it has since been successfully used on tramways at New Orleans, Paris, and elsewhere. I am sorry to have to admit that the progress of mechanical science, so far as it affects locomotives for underground railways, has been absolutely *nil* during the past thirty years. The locomotive at present employed is an ordinary locomotive, worked in the ordinary way, except that in the tunnel the steam is condensed, and combustion is aided by the natural draught of the chimney alone, instead of being urged by a forced blast, as on open portions of the line. Whether a hot water, a compressed air, or a compressed gas locomotive could be contrived to meet the exigencies of metropolitan traffic is a question which, I think, might be usefully discussed at the present or some future meeting of the Association.

A reference to the underground railway naturally suggests the wider question of tunnels in general. The construction of tunnels was not one of the novelties presenting itself to railway engineers, for many miles of tunnel had been driven by canal engineers before a single mile of passenger railway had been built in this or any other country. To foreign engineers belongs the honour of having boldly conceived and ably accomplished tunnel works of a magnitude which would have appalled a canal engineer. I need only refer to the Mont Cenis Tunnel, over 7½ miles in length, commenced in 1857 and finished in 1870; the St. Gothard Tunnel, 9¼ miles in length, commenced in 1872 and finished in 1882; and the Hoosac Tunnel, 4¾ miles in length, commenced in 1854 and finished in 1875. In all cases rock of the hardest character had to be pierced, and it is needless to remark that without the aid of the machinist in devising and manufacturing compressed air machinery and rock-boring plant the railway engineer could not have accomplished his task. Intermediate shafts are not attainable in tunnels driven through great mountain ranges, so all the work has to be done at two faces. In the case of the Mont Cenis Tunnel the mean rate of progress was 257 feet and the maximum 400 feet per month. In the St. Gothard Tunnel the mean rate was 429 feet and the maximum 810 feet. In the Hoosac Tunnel the average rate was 150 feet per month.

Tunnels under broad navigable rivers and estuaries have been a subject of discussion by engineers for at least a century, but the only one at present completed is the unfortunate and costly Thames Tunnel. Two important works of the

class are, however, now well in hand, namely the Severn Tunnel at Portskewet, and the Mersey Tunnel at Liverpool. Having reference to this fact, it will be interesting to quote the following passage from a letter addressed to the press by a Mr. Thomas Deakin on March 6, 1835, that is to say more than forty-seven years ago. Mr. Deakin writes:—'The Great Western railroad from London to Bristol will be accomplished no doubt, and why not continue it under the Severn mouth, near Chepstow, Monmouthshire, through Glamorganshire, and to Milford Haven in Pembrokeshire? It would then traverse the coal-field of South Wales throughout its whole extent—a tract of country possessing also inexhaustible stores of ironstone. A tunnel was once proposed to be formed under the Mersey at Liverpool, and had it not been for the failure of the Thames Tunnel would most probably have been carried into effect.' It is not a little singular that the two tunnels thus foreshadowed by Mr. Deakin should both be in hand at the present moment.

Undoubtedly the numerous accidents which occurred during the construction of the Thames Tunnel, together with its enormous cost of about 1,500*l.* per lineal yard, and the eighteen years occupied in its construction, destroyed the chance of any other projected subaqueous tunnel for many subsequent years. One lesson enforced by the Thames Tunnel was the necessity of leaving a reasonable thickness of ground between the water and the tunnel. In the Severn Tunnel the minimum thickness is 40 feet, and in the Mersey Tunnel 22 feet. The width of the river at the point of crossing of the former tunnel is $2\frac{1}{4}$ miles, and the maximum depth of the rails below high water 163 feet. In the case of the Mersey Tunnel the width is nearly $\frac{3}{4}$ of a mile and the depth 144 feet. The Thames Tunnel, as almost everyone knows, was carried on by means of a special contrivance termed by Brunel a 'shield.' No special appliances have been adopted in the case either of the Severn or the Mersey tunnel. Both are driven in the ordinary way, but of course enormous pumping power is required and has been provided.

Where no special appliances are used in the construction of a subaqueous tunnel, it will be clear to all that an unknown risk is encountered. All may go well, and the engineer will then justly receive congratulations from everyone for his boldness and success. But, on the other hand, something may go wrong, even at the last moment, and I fear the engineer then would be abused no less roundly by the unthinking public for his temerity and consequent failure. It would be a 'Majuba Hill' incident over again, and if the accident caused much loss of life the engineer probably would envy the fate of the brave but ill-starred General Colley, who at least fell with the victims of his rashness.

In many cases of tunnels under estuaries, special appliances could be used which would obviate all risk and make the successful completion of the work a mathematical certainty. A tunnel under the Humber, about $1\frac{1}{2}$ mile in length, projected by myself in 1873, the Bill for which was subsequently passed by the Commons and thrown out by the Lords, was a case in point. The bed of the Humber is of very fine silt, and I proposed to build the tunnel in lengths of 160 feet, under the protection of rectangular iron caissons 160 feet long, by 42 feet wide, sunk by the pneumatic process. As the pressure of the air in the caissons would always be slightly in excess of that due to the head of water in the river, no interruption from influx of water could ever occur, and the operation of building the tunnel in lengths inside this huge diving-bell would be as certain and free from risk as the every-day work of sinking a bridge pier by the pneumatic process.

A tunnel over a mile in length now in progress under the Hudson River at New York is being driven through a silty stratum by the aid of compressed air, and with a certain amount of success, as only some twenty men have been drowned up to the present time. The principle upon which the compressed air is used is, however, a false one, since it is merely forced into the tunnel with a view to uphold the ground by its pressure, like so much timbering, and not to keep out the water on the principle of a diving-bell. It is clear, therefore, that the completion of the Hudson River Tunnel, if the present system be persevered in, is purely a matter of conjecture, and all we can do is to hope for the best. The same remark applies, of course, to the Severn Tunnel and the Mersey Tunnel, although in those cases the

character of the ground is such that the contingencies are small in comparison with those encountered in the construction of the Thames Tunnel and the Hudson River Tunnel. Nevertheless, as I have already observed, unless special appliances of the nature of the pneumatic process be used, a subaqueous tunnel, whether it be the Channel Tunnel itself or one but a few yards in length, must necessarily present an unknown risk. The prototype of all these tunnels is the one commenced at Rotherhithe in 1809, which was successfully driven a distance of 900 feet under the Thames and failed when within little more than 100 feet of the opposite shore. A tunnel about 1½ mile in length was commenced about ten years ago under the Detroit River in America, but was abandoned in a similar manner. So far good fortune has attended both the Severn and the Mersey tunnels, and there is, I am glad to say, every chance of its continuing.

That the series of mishaps with the Thames Tunnel, and the consequent postponement of all other projects for subaqueous tunnels, were due to errors in design and want of foresight on the part of the engineer is patent to everyone now, and was foreseen by at least one acute contemporary of Brunel himself. Only a few months ago, when turning over the leaves of an old periodical, I became aware of the fact that a scheme, identical in all its main features with my Humber Tunnel project, had been suggested for adoption in the case of the Thames Tunnel, in lieu of the plan proposed by Brunel. Writing in December 1823, or fifty-nine years ago, the author of the project, a working smith of the name of Johnson, says: 'I propose to construct the Thames Tunnel without cofferdams by making it in parts, 28 feet in length, each part having the ends temporarily stopped up and being constructed on the same principle as the diving-bell. The men dig from the inside round the edge as if sinking a well, and throw the earth towards a dredger, the buckets of which work some feet below the bottom of the excavation. Each length will be suspended between two vessels and be conveyed to the place where it is to be let down.' A description of the mode of connecting the several lengths is given, and I may add that the tunnel blocks had a sloping face to tend to bring the faces of the joints together, a plan since adopted with the huge concrete blocks at Kurrachee and other harbours. There is not a flaw in the design from beginning to end, as modern experience in the sinking of numerous bridge-piers on precisely the same plan has amply demonstrated. It is beyond all doubt that if the design of this working smith had been adopted in lieu of that tendered by Brunel the Thames Tunnel would have been completed in a couple of years, instead of eighteen years, and at a cost of about 300*l*. per yard instead of 1,500*l*.

If another tunnel be constructed under the Thames, which is far from improbable, as the requirements of below-bridge traffic necessitate some such means of communication, I venture to predict it will be built in accordance with the plan suggested fifty-nine years ago by the working smith, and not on that of Brunel's Thames Tunnel, or of any other tunnel yet carried out.

At the beginning of the present century a committee was appointed to consider the 'practicability of making a land communication by a tunnel under the river Forth, at or near Queensferry.' In a report dated November 14, 1805, it was recommended that a double tunnel should be constructed, at an estimated cost of 164,000*l*., or at the rate of 30*l*. per yard, exclusive of shafts and pumping. The surveyors reporting, grounded their belief in its practicability upon the fact that at Borrowstowness coal-workings had been carried under the same firth for a mile, and that at Whitehaven coal was worked for the same distance under the Irish Sea, in both places less water being met with under the sea than under the land. The report concludes in the following words: 'That a more easy and uninterrupted communication betwixt every part of a country increases the intercourse of commerce, arts, and agriculture, all must know. Ferries are still and often a formidable bar in the road. Of these in this country, the one under review at Queensferry is perhaps the most conspicuous. It is in fact the connecting point betwixt the north and south of Scotland, and indeed of the realm, and in this point of view the improvement of it must be considered a national object.' These words are as true and applicable to the case in 1882 as they were in 1805. A ferry still is the only means of communication across the Forth at Queensferry, though the traffic

has increased a hundredfold. Parliament, by the passing of the Forth Bridge Act during the present session, has given a practical recognition of the truth of the statement in the above-quoted report, that the improvement of the Forth passage is a 'national object.'

As you will receive a paper on the Forth Bridge from my partner, Mr. Baker, I will not trouble you with details of the proposed structure at the present moment. I may state, however, that after a careful consideration of the difficult problem, in concert with my able colleagues, Mr. T. E. Harrison, the chief engineer of the North-Eastern Railway, and Mr. W. H. Barlow, chief engineer of the Midland Railway, we unanimously advised the directors of the Forth Bridge Company to abandon the project for a suspension bridge, and to construct a steel girder bridge of the unprecedented span of 1,700 feet. The total length of the structure is 1½ miles, and it includes two spans, as aforesaid, of 1,700 feet, and two of 675 feet over the navigable channels on each side of Inchgarvie. The execution of the work has been entrusted to me, and my intention is that the Forth Bridge shall be not only the biggest, but the strongest and stiffest bridge yet constructed.

Although great navigable rivers offer the most serious impediments to lines of communication lying at right angles to the direction of the stream, and necessitate such formidable undertakings as the Forth Bridge, with a clear headway of 150 feet above high water, and the Severn Tunnel at a depth of 163 feet below the same datum, still it must be remembered that such rivers were the earliest, and are yet the cheapest, highways for inland communication. Antwerp, the third port in the world, ranking only after London and Liverpool, owes its commercial importance undoubtedly to the Scheldt, which affords admirable water-carriage for a distance of 60 miles from the sea-coast inland. London, similarly, is an inland port situated about 50 miles up the Thames; hence one-half of the distance between Antwerp and London is made up of fine rivers capable of being navigated by the largest ocean-going steamers. The practical result of the existence of this splendid line of natural communication is that iron girders and rails can be conveyed from the heart of Belgium to the metropolis at a far lower price per ton than from any ironworks in this country. Unfortunately, the southern coast of England and the opposite coast of France are indented by no such rivers as the Thames and the Scheldt, or we should never have heard of the horrors of the 'middle passage' in 'cockleshell' boats, or of the Channel Tunnel.

To realise, however, the important part which rivers play in facilitating inland communication, it is necessary to glance at the other side of the Atlantic. In Canada, for instance, we have the great inland port of Montreal, where transatlantic steamers anchor some 500 miles from the coast. The very term 'stream of traffic' suggests a river, and the St. Lawrence well illustrates it. Into some small forest tributary of the Ottawa the lumber-men slide a log of timber, and many months after will that log, with thousands of others, forming together a huge raft, with huts upon it for the accommodation of the care-takers, be found pursuing its slow but ever-continuing progress down the St. Lawrence to Quebec, where it will be shipped to this country.

In Egypt for countless ages the 'ship of the desert' and the boats of the Nile constituted the only means of communication. Wheeled carriages were practically unknown, although as long ago as 1832, Mehemet Ali bewildered the pilgrims by starting off for Mecca across the desert in a Long Acre barouche. But the Nile holds an exceptional position amongst the rivers of the world, for not only was it until quite recently practically the sole means of inland communication for the country through which it flows, but it was, and still is, literally the life of Egypt, since without Nile water there would not be a green spot in the whole of that now fertile land. Having filled the office of consulting engineer to the Egyptian Government for seven years, I have had occasion to give particular attention to the Nile, and I may state that in an average year that river conveys no less than 100,000 million tons of water, and 65 million tons of silica, alumina, lime, and other fertilising solids down to the Mediterranean. The Nile begins to rise about the middle of June, at which time the discharge averages about 350 tons of water per second, and attains in September a height of from 19 feet to 28 feet, and a discharge of from 7,000 to 10,000 tons per second.

Napoleon the Great said that every drop of Nile water should be thrown on the land, and he was right so far as Low Nile discharge is concerned. The cultivated lands in the provinces of Lower Egypt have an area of 3 million acres, and to irrigate this effectually at least 30 millions of tons of water per day would be required, an amount somewhat exceeding the whole of the Low Nile discharge. At present the irrigation canals are totally inadequate to convey this quantity, and imperfect irrigation and consequent loss of crops is the result. In many instances a couple of men labour for a hundred days in watering by shadoof a single acre of ground, all which amount of labour might be dispensed with if the barrage of the Nile were completed, and a few other works carried out, the whole of which would be paid for handsomely by a water rate of two shillings an acre. You will gather, therefore, that I do not think the resources of Egypt have yet been fully developed, magnificent as they even now are, having reference to the size of the country.

It is hardly necessary to say that a network of canals laid out with a view to irrigating the lands of Lower Egypt can also be used at any time in the event of war for the offensive or defensive flooding of the whole or any part of the said lands. Except for the work of man, Lower Egypt for four months in the year would be simply the bed of a river, and for the remaining months a mud bank. Long before the historic period, however, the Nile had been embanked and canals, such as the Bahr-Jusef, had been formed; the first, to keep the floods off the land, except in desired quantities; and the second, to run off the inundation waters as soon as the fertilising matters in suspension had been deposited on the lands. Should the inhabitants of Egypt neglect at any time to maintain the works of their ancestors, successive floods would quickly destroy the embankments and wash the light material into the canals. Thus the whole surface of the country would again be levelled, and the land of Egypt would revert to its primitive condition of being a river's bed for one-third of the year, and probably a malarious swamp for the remainder.

It is hardly possible to refer to Egypt without saying a few words about the Suez Canal. Far-seeing people, including the late Khedive, have long been of the opinion that another ship canal will be required in Egypt. In 1876 I submitted to His Highness, in accordance with my instructions, detailed plans and estimates for such a canal from Alexandria through Cairo to Suez. The total length of the canal was 240 miles, and with the same width as the existing Suez Canal the estimated quantity of excavation was 160 million cube yards.

An interesting and significant incident in the history of the Suez Canal occurred in May 1878, when a fleet consisting of ten steamers and sixteen sailing vessels passed through with 8,412 native troops bound from India to Cyprus. During the same year no less than 58,274 soldiers traversed the Canal. Since 1878 events have marched rapidly, for no one then foresaw that the next important movement of British troops canal-ways would be of a nature hostile in appearance, if not in fact, to the inhabitants of Egypt. The announcement that French and not British troops were to hold the canal was received by the public with an expression of surprise and perhaps of slight resentment, because no one can dispute the vital importance of the work to this country. Periodically the question of the Euphrates Valley Railway is revived, and indeed quite recently I have had to reconsider the question professionally, but this route can never rival the existing one by the Isthmus of Suez.

The inauguration of steam navigation to India was much delayed by the vacillation of the authorities respecting the Suez and the Euphrates Valley routes. Happily, however, the Arabs stole the first bag of mails that went by the Euphrates, and so in 1834 a Committee of the House of Commons finally resolved that 'steam navigation between Bombay and Suez having in five successive seasons been brought to the test of experiment, and the practicability of that line being established, it be recommended to His Majesty's Government to extend the line of Malta packets to Egypt, to complete the communication between England and India.' Nothing appears to have been done during the next two years, but in 1837 a new paddle-wheel steamer, the *Atlanta*, of 650 tons, steamed out to Calcutta round the Cape in ninety-one days and was put on the Red Sea station. She left Bombay with the

mails on October 2nd, 1837, and arrived at Suez on October 16th. The mails were carried across the desert by camels, and down the Nile to Alexandria in four days, where they remained until H.M.S. *Volcano* took them on board on November 7th. At Malta on November 16th they were transferred to H.M.S. *Firefly*, and finally were landed in this country on December 4th, having been in all sixty-three days in coming from Bombay to England. At the present time about eighteen days are occupied in carrying the mails from Bombay *viâ* Brindisi to London.

The town of Southampton, where we are now assembled, has always held a distinguished position in connection with the development of improved communication with our Eastern empire. The opening of the first section of the railway from London to Southampton was coincident with the establishment of steam navigation *viâ* Egypt to India, and in the same year the French engineers at Cairo completed their studies for the proposed railway across the desert to Suez.

A few months later the London public were startled by an advertisement headed 'Steam to New York,' and 94 passengers were plucky enough to embark at London, on April 4th, 1838, in the *Sirius*, of 700 tons and 320 horse-power, for New York, where they arrived on the 23rd, having performed the voyage in seventeen days from London, and fifteen days from Queenstown. The *Great Western* sailed from Bristol on April 7th, and arrived at New York a few hours after the *Sirius*, and thus was the great problem of steam navigation to America successfully solved, by vessels of small size, and capable of maintaining a speed of but 8 to 9 miles an hour. I need hardly remind you that since the year 1838 the ships conducting the enormous traffic between Europe and America have been of ever-increasing size and speed. Thus the *Britannic*, built in 1874, has an extreme length of 468 feet, a beam of 45 feet 3 inches, a displacement of 8,500 tons, and a speed of 16 knots per hour; whilst the *Servia*, built in 1881, has an extreme length of 530 feet, a beam of 52 feet, a displacement of 13,000 tons, and a speed of 18 knots, and the *City of Rome*, built in the same year, has a length of 600 feet, a beam of 52 feet 3 inches, and a displacement of 13,500 tons. Another Atlantic liner, the *Alaska*, having a length of 500 feet, a beam of 50 feet, and a displacement of 12,000 tons, attained a speed of 18½ knots on the measured mile, and has done the distance between Queenstown and New York in seven days four hours and thirty-two minutes, and the return voyage in six days and twenty-two hours, a mean ocean speed of, say, 17 knots per hour, or more than double that of the first steam-vessels trading to America.

The present generation has grown so accustomed to the embodied results of the progress of mechanical science, that it has long ceased to wonder at big ships, or at any other novelty. To realise what has been attained it is necessary to place ourselves as far as possible in the position of our immediate ancestors, and to look at things through their spectacles. With this view, and to give you some scale of comparison to measure the size of the present Atlantic liners by, I will quote a short passage from a newspaper of September 19, 1829, where reference is made to a vessel then under construction, of about the size of one of the much-abused 'cockleshells' performing the Channel service between Dover and Calais. 'The Dutch have been engaged for the last five years in constructing and equipping a steam-boat of extraordinary magnitude, in order to facilitate the communication between Holland and Batavia. It has four masts; is about 250 feet long; and has been appropriately christened the *Monster*. In consequence of her great length, she hung when going off the slips, and it was some days before she was fairly launched; a circumstance which gave the wits of Paris occasion to remark that their Dutch neighbours were so determined to excel all other nations in the magnitude of their steamboats, that they had built one so long that it was several days running off the stocks. One of the most remarkable features of this enormous vessel is her extreme narrowness as compared with her length; her greatest breadth of beam being only about 32 feet. The great size of this vessel will bring to the recollection of our readers the *Columbus*, which was built in the river St. Lawrence in 1824, and made the passage to England in safety, but was afterwards broken up on account of her unmanageable bulk. We shall not be surprised to find that a similar fate awaits the *Monster*, and for a similar reason.'

The Channel boat *Albert Victor*, now on the Folkestone station, is of the same length as the *Monster*, namely 250 feet, whilst the beam of the former is but 29 feet, instead of what the critic of 1829 termed the 'extreme narrowness' of 32 feet.

The successive attempts at mitigating the discomforts of the Channel passage by the swinging saloon and twin-steamers of Sir Henry Bessemer and Captain Dicey have gradually prepared the way for what I believe will be the next and important step of establishing Channel communication by means of large floating stations, or ferry-steamers, capable of traversing the narrow sea between England and France in little more than an hour. Ten years ago I applied to Parliament for powers to carry out this project, and obtained the unanimous sanction of a Committee of the House of Commons. The Bill was, however, thrown out in the House of Lords by the casting vote of the chairman.

What was practicable at that time has now become comparatively easy, owing to the introduction of steel into shipbuilding, and the improvements which have been effected in marine engines and mechanical appliances generally.

Whether the over-sea or under-sea mode of crossing the Channel—the ferry or the tunnel—is to be the adopted scheme, will soon be determined. It may be that both will be carried out, and then at least all tastes will be met, and all anticipations respecting the resulting increase in traffic, both in goods and passengers, between the two countries will be brought to the test of experience. However this may be, I am very pleased to be able to announce that my friends Mr. Abernethy and Mr. Clarke Hawkshaw will read papers on the subject, the former on the over-sea, and the latter on the under-sea plan, and I shall be disappointed if the papers do not lead to an interesting and valuable discussion.

In few departments of the engineer's work has such progress been made as in that of steam navigation. When in 1820 steamships were first used for conveying merchandise as well as passengers, the tonnage of the whole of the steam traders of this country, it is stated, amounted to but 505 tons. At the present time the corresponding figure is 2½ million tons. Did time permit I would say more on the subject, but I fear that in speaking at all upon steamships I have departed somewhat from my avowed intention of keeping within the sphere of engineering, in which I have chiefly worked. My apology must be that a discussion of railways led me to a consideration of tunnels and bridges, and this naturally suggested a reference to the rivers necessitating the construction of the said tunnels and bridges. From river traffic to ocean traffic is but a step, and so I have been insensibly led to touch upon the wonderful results achieved in recent times by naval architects and mechanical engineers.

I will not similarly err in troubling you with any remarks of mine upon the no less wonderful results achieved by electricians. A description of the work done by my friend Dr. Siemens during the past quarter of a century would in itself constitute a concise history of electrical science. Remembering, however, the warning of King Solomon, that 'He who praiseth his friend with a loud voice, it shall be counted a curse to him,' I will refrain from referring to Dr. Siemens, or to my immediate predecessor in this chair, Sir W. G. Armstrong, and conclude my address at once with a sincere wish that the present session of the British Association may prove not less interesting and productive of benefit to science than have any of those which have preceded it.

The following Papers were read:—

1. *On the Forth Bridge. By* B. BAKER.—See Reports, p. 419.

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2. *On the Treatment of Steel for the Construction of Ordnance, and other purposes. By* Sir WILLIAM ARMSTRONG, *C.B.*, *F.R.S.*—See Reports, p. 398.

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3. *On the increased Tenacity in perforated Test Bars of Steel and Iron.* *By* T. Wrightson, *M.I.C.E.*

The author quotes the experiments of Professor Kennedy,[1] and of Mr. Edward Richards,[2] as to the curious fact, that a drilled test bar has a greater tenacity per square inch than a plain bar, and proceeds to propound a theory as to the cause for this apparent anomaly.

If a plate or bar under tensile test be supposed to consist of a series of molecular chains or filaments parallel one to another, but disconnected laterally except at the ends, then, as the test proceeds, each filament being equally loaded would extend without affecting its neighbour. Again, if horizontal filaments be supposed to connect the longitudinal filaments, these will descend as stretching takes place, but will not affect the relative position of the longitudinal filaments.

If, however, we suppose diagonal connections to exist between the upper end of the extreme and the centres of the opposite filaments, it is evident that when, through stretching, the centres of the longitudinal filaments descend, either an elongation of the oblique filaments or a drawing in of the longitudinal filaments must occur. The resistance of the latter in this direction being small, a lateral movement takes place. The author contends that the well-known phenomenon of contraction in a test bar arises from this cause, and is due to the oblique connection of the longitudinal filaments.

Assuming this view of the phenomenon of contraction to be correct, the author supposes a hole drilled in the centre of a test bar, and shows that the two sections left should be capable of resisting more than the same section in a single bar because the contraction of area in the former case is resisted by the material immediately above and below the hole, which must be stretched horizontally before the adjacent iron can contract to its full extent. Hence the area being partially maintained by the action of these cross strains the bar should be stronger. That this is so has been abundantly proved, but the author goes further in describing an experiment showing that in drilling several holes in a line across the bar, the tenacity increases with an increased number of holes. Thus an iron bar two inches wide by half inch thick broke at 22·68 tons per square inch of original area. When an inch hole was drilled in the centre of a test piece cut from the same bar the tenacity increased to 22·93 tons. Two holes half an inch in diameter increased the tenacity to 24·82 tons. Three holes one-third inch diameter increased the tenacity to 24·99 tons, or about 10 per cent. total increase, comparing the plain bar with that perforated with three holes cutting away half the section.

These facts show that the form of a test bar may be such as to bring into action the cross fibres of the material in such a way as considerably to affect the results obtained.

FRIDAY, AUGUST 25.

The following Report and Papers were read:—

1. *Report on the Committee on Patent Legislation.*—See Reports, p. 310.

2. *The Channel Tunnel.* *By* J. Clarke Hawkshaw, *M.A.*, *F.G.S.*, *M.I.C.E.* See Reports, p. 404.

3. *A System of Excavating the Channel Tunnel by Hydraulic Machinery.* *By* T. R. Crampton.

The chalk from the cutters is received into a revolving drum, to which also the waste water from the hydraulic motor employed to drive the machinery is led.

[1] *Proceedings of Mechanical Engineers,* April 1881.
[2] *Proceedings of Iron and Steel Institute,* May 1882.

The chalk is turned into a cream or sludge, which can be pumped out and delivered at the mouth of the tunnel or elsewhere.

4. *Improved Continental Communication.* *By* JAMES ABERNETHY, *C.E.*

The author proposed to establish a service of large steamers between Calais and Dover, on which entire trains could be conveyed across the Channel. The steamer would be 470 feet in length; 60 feet beam; 6,000 tons; with engines of 12,000 indicated horse-power; the draft loaded to 12 feet; estimated speed, 23 miles. It is thought that vessels of this size would not feel any movement in the Channel. The cost for three steam-vessels, and the necessary works at Dover and Calais, was estimated at a million and a half.

5. *On Unsteady Motion in Open Channels.*[1]
By MAJOR ALLAN CUNNINGHAM, *R.E.*

The motion of water in open channels is essentially an *unsteady motion with interlacing stream-lines*; the hypothesis of steady parallel motion is at variance with nature.

Single velocity measurements are of little practical use, being only accidental values; the average of a large number is pretty constant, so that the *average velocities* should always be sought. The time needed to obtain these involves a chance of change of the external conditions.

In practical hydraulics the forward velocity is the only velocity considered or required. Floats measure this directly; no other instruments yield this quantity readily in large streams.

These principles are of great importance, and show that hydraulic experiments must always be tedious and expensive.

6. *Convexity of Surface of Streams.*[2] *By* Major ALLAN CUNNINGHAM, *R.E.*

The figure of the transverse section of the free surface of a stream, usually supposed to be convex, is here considered. The evidence is shown to be very small. Some new special experiments are cited. The conclusion is that the surface is probably level across.

7. *Depression of Maximum Velocity.*[3] *By* Major ALLAN CUNNINGHAM, *R.E.*

The line of maximum velocity in an open channel is usually below the surface. The cause of the depression is obscure. The wind and disturbances from the banks and bed are usually supposed to be the causes. The wind is probably too inconstant. The disturbances from the banks and bed seem an inadequate explanation. The general depression of the maximum velocity on all verticals at all parts of a channel indicates some resistance from above. The motion in open channels and in pipes flowing full shows some similarity, with differences in detail fairly accounted for by supposing the air to be an ever-present drag or source of resistance to forward surface-flow less efficient than the banks or bed. If this be admitted, the hydraulic term, 'wet border,' must be modified so as to include *all parts* of the wet border, each with its own specific resistance.

SATURDAY, AUGUST 26.

The Section did not meet.

[1] See *Roorkee Hydraulic Experiments*, by Major Allan Cunningham, R.E. Roorkee, 1881. Vol. i. ch. vi.

[2] *Ibid.* vol. i. ch. viii. [3] *Ibid.* vol. i. ch. xii.

MONDAY, AUGUST 28.

The following Papers were read:—

1. *On Compressed Air as applied to Locomotion. By* Sir FREDERICK BRAMWELL, *F.R.S.*

This paper consisted of a description of a tram-car on the Mekarski system now employed at Nantes in France. A car on a similar system is being constructed for trial on the tramway running from King's Cross to Holloway. The gauge of the French line is 4 feet 8½ inches, the wheel base of the car being 5 feet 9 inches. The principal features of the engine consist in the use of what is termed a 'hot pot,' and in an automatic regulating valve. The hot pot is a receptacle containing hot water and steam under pressure, and through this the compressed air is allowed to bubble on its way from the receivers to the cylinders, so that it may be expanded in the cylinders without risk of the formation of snow. The automatic regulating valve is set on the top of the hot-water vessel. A hand-wheel lowers or raises a plunger; this acts upon the liquid contained between an elastic india-rubber diaphragm placed a little below the plunger and the upper part of the vessel. Just around the plunger there is an annular air-space acting as an air-vessel. When the plunger is depressed into the liquid, the result is to compress the air in the air-vessel to any desired extent. Then, as the hot pot is always in connection with the reservoirs in which the compressed air is contained, when the outlet air cock on the regulating valve is opened, air bubbles through the hot water and rises past the cone valve which is attached to the diaphragm, and presses on the under side of the diaphragm, tending to raise it; but it cannot succeed in doing so until the pressure of the air below the diaphragm equals that in the annular air-vessel above, and thus the pressure in the annular air-vessel is automatically the measure of the pressure that will prevail in the engines. So soon as this is exceeded the diaphragm rises and closes the valve; and so soon as it falls the air in the annular air-vessel re-expands, presses down the diaphragm, opens the conical valve, and lets in more compressed air. The driver is thus enabled to vary the pressure, while the pressure, whatever it may be, is maintained steady, whether the engines are running fast or slow.

The working of the engines was very satisfactory. There was no smoke, no escape of the steam, no noise. The exhaust air is let into a box, from whence it escapes quietly just above the level of the road. So far as can be judged from outside appearance there is scarcely anything to distinguish one of these cars from an ordinary horse tram-car. The compressed air reservoirs are charged at one end of the journey. For this purpose four horizontal condensing steam-engines are used, each of about 20 nominal horse-power. Each engine works two single-acting air-pumps. The first air-pump compresses to six atmospheres, the second draws from the first and compresses to thirty. While the compressed air is being charged into the receivers, steam is turned into the hot pot, so as to heat the water, a certain quantity of the water being, when necessary, allowed to run out. According to information given to the author, it appeared that the cost of working the line on this system was less than the cost of horse-power, and the system had besides several other advantages.

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2. *Recent Progress in Telephony. By* W. H. PREECE, *F.R.S.*

This paper gave an account of the progress made in the construction of telephonic apparatus since the telephone was introduced to the British Association in 1877. The author described the principal forms of telephone receivers and transmitters, including those of Ader, Gower, Dolbear, Edison, Blake, and others. He also described the arrangements which have been made to diminish induction on busy lines, and thereby to get rid of the noise which is the chief difficulty in transmitting articulate speech. The only really successful plan was that of employing a complete metallic circuit instead of using the earth for the return circuit, and twisting together the two wires composing this circuit. In concluding, the author

gave an account of an experiment lately tried, by which communication had been effected between Southampton and the Isle of Wight across the Solent, the object being to try the possibility of establishing communication across seas and channels by telephone without the aid of wires. Large metal plates were immersed in the sea at opposite ends of the Solent—namely, at Portsmouth and Ryde, six miles apart, and at Hurst Castle and Sconce Point, one mile apart. The Portsmouth and Hurst Castle plates were connected by a wire passing through Southampton, and the Ryde and Sconce Point plates by a wire passing through Newport; the circuit was completed by the sea, and signals were passed which could be read by the Morse system, but speech was not possible.

3. *On a new Arc Lamp.* *By* W. H. Preece, *F.R.S.*

This is the invention of M. Abdank, a Polish professor residing in Paris. He separates the regulator of the current from the lamp itself, and fixes it anywhere within easy inspection and manipulation. The regulator is a differential balance, and it acts like the key of a Morse apparatus, which sends automatically short, rapid, successive currents through a local break, so as to allow the top carbon to fall by very minute movements as it is consumed. The carbon is continually falling by a motion invisible to the eye, but sufficient to provide for the consumption of the carbons. It is a remarkably constant and steady arc lamp. Regulation by small and successive steps automatically controlled is believed to be a new principle.

4. *Recent Progress in Electric Railways.* *By* Dr. Fleming.

This paper described Edison's railway at Menlo Park, which the author said saved about 1 lb. of coal per hour per horse-power as compared with the ordinary locomotive.

5. *On Electric Light Engineering.* *By* Dr. Fleming.

6. *On the Efficiency of the Edison Steam Dynamo.* *By* Dr. Fleming.

7. *On some Apparatus for use in connection with Electric Light Measurement.* *By* Robert Sabine.

The writer gives an account of four pieces of apparatus devised for the purpose, viz:—

1. A photometer.
2. A current dynamometer.
3. A potential dynamometer and resistance measurer combined.
4. A mean-pressure indicator.

The principle employed in the photometer is that such a thickness of some absorbing material is placed in the path of the rays of each of the two lights under comparison as will partly equalise the two lights, the final adjustment being made by the alteration of the relative distances of the lights from the photometer. The current dynamometer is formed of two flat coils, one of which is suspended, and the other arranged to slide along a scale. Suitable arrangements are made for allowing the current to pass through the whole system. The repulsion between the coils results in the deflection of the suspended coil. The sliding coil is then shifted until the two coils are parallel. The paper describes the way in which the scale is graduated, and the arrangements for observing the deflection of the suspended coil.

The potential dynamometer and resistance measurer consists of two circular coils of moderately fine copper wire, one of which is held by a bifilar wire suspension inside the other, as in Weber's well-known dynamometer, an adjustable resistance being inserted to reduce the deflections to a constant value. When required, however, to be used as a galvanometer the suspended coil can be readily removed and replaced by a magnet needle. The object of the mean-pressure indicator is to

allow the mean pressure at either end of the cylinder to be read off by the use of a Bourdon pressure-gauge. A pressure-gauge is mounted at each end of the cylinder, the pipe leading to the gauge being throttled so as to allow a small entry and exit of steam at each stroke. This throttling causes the pointer of the gauge to rise gradually to the mean pressure, above or below which it makes small oscillations. To prevent condensation in the throttle or tube, these are kept hot by the flame of a lamp placed below.[1]

8. *On a new form of Arc Lamp.* *By* Professor G. Forbes, *M.A.*, *F.R.S.E.*

This is a focussing arc lamp. The carriers of the two carbons are supported by vertical racks which are worked by pinions, one of which is twice the diameter of the other. These pinions are on the same axis as the ring of a small Gramme motor; a current is supplied to this ring by a shunt from one on the main wires. One field magnet of the motor is wound with thick wire and is in the main circuit; the other is wound with fine wire. It is connected as a shunt on the arc.

9. *On the Laws defining the Strength of Current which can be sent through Wires of different diameters without raising the external temperature above a certain limit.* *By* Professor G. Forbes, *M.A.*, *F.R.S.E.*

Law I.—When the wire is bare and exposed to the air, the strength of current is more nearly proportional to the diameter of the wire than to the theoretical value of the diameter raised to the power $\frac{3}{2}$.

Law II.—When the wire is wound in coils of the same size and weight, the strength of current is proportional to the square of the diameter of the wire.

To find out the first law, a trace of wax was put upon the wires, and the current necessary to melt it was measured.

To find out the second law, thermometers were inserted in coils of equal size and weight, and the currents required to raise each to the same temperature were compared.

TUESDAY, AUGUST 29.

The following Report and Papers were read:—

1. *Report of the Committee on Wind Pressure.*—See Reports, p. 315.

2. *On the Mechanical Properties of Aluminium.* *By* W. H. Barlow, *F.R.S.*

A bar of aluminium, three feet long and a quarter of an inch square, was obtained, and different parts of this bar were subjected to test for tension, compression, and transverse strain; and also to ascertain the modulus of elasticity, the elastic range, and ductility.

It will be seen on reference to the results obtained, that the weight of a cubic inch is ·0275 lbs., showing a specific gravity of 2688, and that its ultimate tensile strength is about 12 tons per square inch. The range of elasticity is large, the extension at the yielding point being $\frac{1}{200}$ part of its length. The modulus of elasticity is 10,000. The ductility in samples 2 inches long was 2·5 per cent.

Taking the tensile strength of this metal in relation to its weight, it shows a high mechanical value. Its characteristics in this respect, as compared with those of other well-known metals, are shown in the following summary:—

[1] *Electrical Review*, vol. xi. p. 197.

	Weight of a cubic foot in lbs.	Tensile strength per square inch in lbs.	Length of a bar which is just capable of bearing its own weight.
			Feet lineal
Cast iron	444	16,500	5,351
Bronze	·525	36,000	9,893
Wrought iron	480	50,000	15,000
Steel of 35 tons per inch	490	78,000	23,040
Aluminium	168	26,880	23,040

It thus appears that, taking the strength of aluminium in relation to its weight, it possesses a mechanical value about equal to steel of 35 tons per inch.

3. *On the Southampton Docks.* *By* A. Giles.

The paper gave a short history of the Docks since they were commenced in 1838. They were opened in 1842. Additions were made in 1845, 1851, 1853, 1859, 1873, and 1879. At present, one of the dry docks is being lengthened from 400 feet to 500 feet to accommodate larger steamers. In the concluding part of his paper, the author compared the respective advantages as ports of Southampton and London.

4. *On the Reclamation of Brading Harbour.* *By* R. F. Grantham, *Assoc. M.I.C.E.*

This paper contains an account of the works in connection with this undertaking.

Reference is first made to the attempt of Sir Hugh Middelton in 1620, to enclose the harbour, an area of about 700 acres, uncovered at low water. The line of the embankment as laid out by him has been traced by the discovery of the piles of oak which were then used. The attempt was successful for a time, but the land was found to be not so good as was expected, and although crops of wheat, barley, oats, cabbage seed, and rape seed were sown, no produce was obtained except from the rape seed.

In a few years the sea broke in, and the land was again until 1879 continually inundated at high water.

In 1874 a company entitled the Brading Harbour Improvement and Railway Company was formed, and in 1877 the work of constructing the embankment was commenced. The paper describes the form of the embankment and the difficulties met with and failures experienced in closing the Bembridge end, and also gives particulars of the methods adopted in piling and planking the gap.

The sea was shut out in July, 1879, but in the following October again broke in. Further attempts were made to close the gap, and at length the sea was finally shut out at the end of February, 1880. The line of the present embankment encloses an area of rather more than 600 acres. The works of lowering the sluices, the inverts of which were found to be at too high a level, and of the wharves erected at the St. Helen's end of the embankment, are also referred to, as well as the new channel for the river Yar in course of execution across the reclaimed land.

The author states his opinion that permanent pasture is the proper treatment for reclaimed lands of that description.

The reclamation works were undertaken not solely for the purpose of recovering the land from the sea, but also with the object of improving the harbour, and establishing a port for the trade on that side of the island, as well as opening up the villages of St. Helen's and Bembridge.

5. *Improvements in Gas Illumination.* *By* W. Sugg.

This paper dealt with the faults existing in ordinary gas-burners, and the points required in the construction of a good burner. The author showed that a much

better effect could be obtained by the use of Argand burners with chimneys, than from any burner of the ordinary flat flame type. The paper concluded with some remarks on ventilation, and on the way in which heat generated by the combustion of gas could be utilised for ventilating purposes.

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6. *On Sound Signals. By* E. PRICE EDWARDS.

The purposes for which such signals are employed are chiefly in connection with railway and sea travelling. No recent improvement as regards railway sound signals can be recorded, but there has been a great development of late years with marine sound signals. Railway whistles are very distressing to the public; not so to the callous engine-drivers who use them without any regard to the public comfort. This is a matter which might be ventilated by the press, for there is a great deal of unnecessary whistling, and there is no necessity for the use of the piercingly shrill sounds which are commonly employed in this country. The explosive signals used in foggy weather are admittedly inefficient and costly, besides being annoying to railway travellers. For signals between ships at sea, the recent alteration of the regulations for preventing collisions has necessitated the use of sound signals to a considerable extent, and various instruments operated by manual labour have been devised to meet the requirements as regards sailing vessels; steamers of course use the steam whistle. For coast fog-signals there has been a great progress made of late years; whistles are not used for this purpose, reed horns have been discarded, and now sirens and explosives only are used. A novel feature of late with the siren is the introduction of two notes, as a means of distinction. Each signal is to have a combination of high and low notes so that it may proclaim its own individuality and be readily recognised. It is also proposed to make double explosive signal rockets, by means of which a further distinction may be made for this class of sound signals.

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7. *Some of the Causes of Collision at Sea. By* Captain COLOMB, *R.N.*

The causes assigned in the Annual Wreck Register, according to the official statement for the year 1879–80, were divided into two classes:—(1) conditions which are irremediable and inevitable; and (2) the moral obliquities of seamen. The former comprise 40 per cent., and the latter the remaining 60 per cent.

The classification is unsatisfactory because collisions can rarely be set down to a single cause; and because, though inevitable conditions are always present, they do not necessarily produce inevitable accidents.

There has never yet been any public enquiry into the causes of collision, nor any official statement of the conditions under which they happen, further than the state of the atmosphere and sea, and the question of whether darkness or daylight prevailed. Contrary to what might have been supposed, a thick atmosphere does not increase, but generally markedly decreases the number of collisions; while, as might be supposed, the greater number of accidents, and those which are most disastrous, happen at night. It is convenient to confine the attention to these latter.

It has been found by examining carefully considerable numbers of collision cases which have been tried in the courts, that in only about 7 per cent. of them were the ships first seen at a greater angle to the direction of the courses steered than 45°; and in only about 26 per cent. of the cases did the two ships' courses cross at a greater angle than 45°. The normal condition previous to collision is when the courses of the two approaching ships are nearly, but not quite, opposite. Collisions under any other conditions are rare. The conditions of sea traffic make it quite certain that one or both ships approaching under these conditions turn towards each other. But such a movement or movements very rarely indeed precede collision. On the other hand, the contrary movement of one or both ships turning away from the other is nearly always found preceding collision.

Constantly improving experiments have been made to measure exactly in time and space the movements of ships under the action of their rudders. It is found

that they turn in a path which is a spiral whose least radius is seldom less than two or three times the length of the ship.

Ships are from four to ten times as long as they are broad. The target a ship offers to be struck by another, is from four to ten times as large when the broadside is offered to the blow as when the stern is offered; and the effect of the bow of one ship on the broadside of another is much more destructive than when bow strikes bow.

The movement of a ship in turning *away from* another which is crossing her course from ahead under the ordinary conditions precedent to collision, tends to present the maximum, and the most tender target to be struck, and it destroys the possibility of reversing a wrong movement. The movement in turning *towards a ship* under like conditions tends to present the minimum and the least tender target.

No idea could be more natural to the unreflecting than to suppose that turning away from an approaching danger was the proper way to avoid it. What alone makes this dangerous are the limits by which the manœuvring powers of ships are controlled; and the fact that their transverse section is so very much smaller than their longitudinal section.

It is the same with these opposite movements in fogs. The tendency of the seaman is to turn away from the fog-signal which denotes on his right or left an approaching ship, but such a movement is always a precedent of collision.

Minor causes producing a further ultimate cause of collision are found under the following conditions. Ships approaching one another as described are seldom equally distant, either in space or time, from the point at which their courses would if produced intersect ahead of both. If the ships have equal manœuvring powers, the one which is farthest from this collision point, as it has been called, is much more capable of avoiding a collision than the one which is nearer. If the distance apart of the ships is small, it becomes absolutely impossible for the ship which is nearest to the point to avoid the other, while it is easy for the ship which is furthest from the point to avoid the other by turning towards her. The modern law takes no account of these conditions, which the old rule of the sea fully recognised, and in half the number of cases forbids, as far as it does anything at all, the ship which alone has the power, to make the movement which is necessary to their mutual safety.

Minor proximate causes leading up to and producing these ultimate movements and conditions, and through them collisions, are found in the multiplicity of distinctions which exist in the law. The rule of the road at sea has grown to be very complex, and in the anxious state of mind produced by possible collision, the seaman sometimes calls up and acts on the wrong rule. No one who has ever been subjected to this anxiety will readily blame the seaman who makes a mistake.

Another minor cause proceeds from the complexity and indefiniteness of the appliances which have grown up under the law. This latter being complex and various has necessitated differences and distinctions in the lights and signals, not in themselves necessary and leading to constant mistake. The latest development of this complexity is for the present in suspense; but it is remarkable that a single white light has under the present law no less than four totally different meanings, and yet if the wrong meaning is attached, a wrong movement and a collision may follow. In some signals by sound, the *timbre* of the note is the only distinction, while there is nothing to prevent that present distinction from becoming obliterated.

The removal of these causes of collision is only difficult in practice. Changes in rules which are international would be required, but as changes have often been made before, and even quite recently, while some are still pending, there can be no real difficulties. If the conditions and movements antecedent to collision were authoritatively stated and classified, it would be seen to be easy to alter the law so as to aim directly at their removal.

Nor is it difficult to see what the nature of the change would be. There would be a return to the sound rules and teaching of the old law, a removal of the complex distinctions and the complex appliances which the new law has made necessary, and a simplicity of rule which would never mislead the seaman called on to act rightly in moments of supreme surprise and apprehension.

8. *On the Engine Power Meter.* *By* C. VERNON BOYS.

The quantity of work done by steam or other fluid on the piston of an engine is found by multiplying at every moment the rate of movement of the piston by the difference of pressure on its two sides, and continuously adding the products. This quantity is usually determined in any one complete stroke of an engine by finding the areas of the indicator diagrams taken at each end of the cylinder, and adding them together. This is a measure of the whole work done in that stroke. In the same way the work done in any other stroke may be determined. If the engine is working any length of time at a uniform rate against a constant load, the total quantity of work done in that time may be found by multiplying the number of strokes by the work done in one. Practically this cannot be done; therefore, if it is desired to find the work done during any length of time, some form of engine-power meter must be used. At the present time, when the efficiency of machines is attracting so much notice, any advance in this direction is of importance.

In the author's instrument the difference of steam-pressure is determined by a differential pressure gauge, consisting of a piston in a cylinder controlled by a spring. The two ends of the cylinder communicate by pipes with the two ends of the cylinder of the engine. This cylinder is separated from the box containing the calculating mechanism by an air space, so that heat and dirt are effectually excluded. The piston rod enters the box at the middle of the base, and passes through to the top, where the spring is attached which lies in a tube attached to the top of the box. On the piston rod is a sleeve carrying two pins, one working in a guide to prevent the sleeve from turning when the piston rod turns slightly, and the other to give inclination to what is called the tangent wheel. This is a small wheel with its edge in contact with the surface of a cylinder which is free to travel longitudinally and to rotate. If the plane of the tangent wheel is parallel to the axis of the cylinder, then when the latter moves longitudinally, there will be no rotation, but if the tangent wheel is inclined, the cylinder will rotate with a speed proportional to the tangent of the inclination multiplied by the rate of the longitudinal movement. If the pin on the sleeve of the piston rod works in a radial slot in the tangent wheel frame, then the tangent of the inclination of the latter will always be proportional to the displacement of the piston rod, and therefore to the difference in pressure in the engine cylinder. Now if the integrating cylinder is moved in time with, and in proportion to the motion of the engine-piston, the rate of turning of the integrating cylinder will be proportional to the rate at which work is being done, and the number of turns shown by a counter will be a measure of the total amount done during any length of time. There is no necessity to adjust the tangent wheel to absolute parallelism with the axis of the cylinder when there is no steam-pressure; even if considerably inclined, there will be no accumulating error, for whatever error is introduced during a forward stroke is absolutely removed during the return stroke.

WEDNESDAY, AUGUST 30.

The following Report and Papers were read :—

1. *Report of the Committee on Screw Gauges.*—See Reports, p. 311.

2. *Torpedo-boats.* *By* J. DONALDSON, *M.I.C.E.*[1]

The author pointed out the great advance that had been made in the construction and armament of torpedo-boats since the American Civil War, and the

[1] Published *in extenso* in the *Engineer* Sept. 29, and in *Engineering* October 13 and 20.

recognised position which the torpedo-boat had now attained as an engine of warfare.

He then described, in detail, with the aid of models and diagrams, the two distinct groups into which the various types of torpedo-boats have gradually been resolved, viz., those attached to and carried by larger vessels, to which they would act as auxiliaries; and those sufficiently large to act independently, and, to a certain extent, to keep the sea, which would be used for harbour and coast defence. These two groups have been named, by the English Admiralty, the first and second-class groups, respectively.

The dimensions of the present English second-class boats are:—Length, over all, 63 ft.; beam, 7 ft. 6 in.; draught of water, 3 ft. 4 in.; displacement, $12\frac{1}{2}$ tons. The hull is constructed of Bessemer steel, galvanised, and is divided into ten compartments by means of bulkheads and half-bulkheads. The machinery consists of a pair of compound surface condensing-engines, having cylinders $8\frac{1}{4}$ in. and 13 in. diameter respectively, by 8 in. stroke; giving 150 indicated horse-power at a speed of 653 revolutions per minute, corresponding to 17·65 knots per hour, the maximum measured-mile speed attained by these boats. The surface condenser is of copper, tinned inside, and the condensing water is supplied by means of a centrifugal pump 8 in. diameter, driven by a separate engine. The boiler is of the locomotive type, the shell being made of steel with a copper fire-box and brass tubes, strong enough to withstand a water-pressure of 260 lbs., and a working pressure of 130 lbs. per sq. in. The area of the fire-grate is 6·6 sq. ft., and the heating surface 268 sq. ft. The stokehold is entirely enclosed, and the air is supplied to the boiler by means of a fan, driven by an independent engine, which at a speed of 800 revolutions per minute gives a pressure of from 2 to 3 in. of water. The stokers are kept cool and comfortable by the large volume of air passing through, and to provide for their safety the fire-door of the boiler is made to shut tight; the ash-pan is cased in with a light casing, having flaps in front opening inwards, which would close on any undue pressure, such as would arise from the bursting of a tube or other sudden leakage in the boiler; and an escape, closed at normal pressure by a door fastened by a spring, is carried up to the deck. By means of a nozzle fitted into the bottom part of the barrel of the boiler, and a pipe carried to the deck, the boiler of the boat can be connected with the ship's boiler, and a steam-pressure of 60 lbs. raised in about $9\frac{1}{2}$ minutes, by which time the fan, also driven by the borrowed steam, has brought the fire into condition to maintain that pressure.

These boats are fitted with an ejector in the stokehold, capable of ejecting 45 tons of water per hour. The centrifugal pump can be utilised for emptying the bilges, and the two together would eject the whole displacement of the boats every ten minutes. The lifting weight of the boats all on board is $12\frac{1}{2}$ tons, and the lifting is effected by means of slings, attached to hoops on the bulkheads forward of the boiler-room and aft of the engine-room.

The second-class boats, built or building by the author's firm for the Danish and Italian Governments, are substantially the same as the English second-class in hull, engines and boilers; but in the Danish boats the pumping is done by ejectors alone, six of which are fitted in different parts of the boat, and are capable of ejecting the whole displacement every $5\frac{3}{4}$ minutes. The ease and readiness with which an ejector can be turned on in any compartment without the necessity of communicating with the engine-room are a strong recommendation in favour of that method of pumping. All second-class boats now carry two 14-in. Whitehead torpedoes, and the Danish and Italian also carry two-barrelled Gardner machine-guns.

There are three methods of ejecting the torpedoes. The earlier English boats are fitted with davits and discharging frames, so arranged that the frames can be lowered over the side, close to the boat and parallel to its centre line, to a depth of 2 ft. under the surface of the water. In this system no external impulse is used; the pulling of a lanyard liberates the torpedo and starts its engine.

This system has been superseded in the later English boats, in which the torpedoes are laid all ready for discharging in two troughs on the forward part of the deck, and are projected therefrom by means of two pistons and rods working

in steam cylinders $4\frac{3}{4}$ in. diameter, by 7 ft. stroke. This system has given excellent results in experiments at Portsmouth.

In the later Danish and Italian boats the troughs have been replaced by tubes from which the torpedoes are ejected by compressed air stored in reservoirs and admitted into the tubes behind the torpedoes. Besides other advantages possessed by the air-impulse system, so long as the reservoirs and torpedoes are charged, the boats may be used independently of steam being up in their boilers, and would thus serve as so many launching tubes on the ships to which they are attached.

Coming to the first-class boats, these, in general construction, hull, engines, and boilers, resemble the second-class type, but are, of course, on a larger scale.

The dimensions of most of the Admiralty first-class boats are:—Length over all, 87 ft.; beam, 10 ft. 10 in.; draught of water, 5 ft. 2 in., with a displacement of 32·4 tons. That, however, represented by the model was 90 ft. 6 in. over all, by 10 ft. 10 in. beam, and, like the rest, was fitted with engines having cylinders $12\frac{3}{4}$ and $20\frac{7}{8}$ in. respectively in diameter by 12 in. stroke, which, on trial, gave indicated horse-power 469 at 443 revolutions per minute and speed $21\frac{3}{4}$ knots per hour.

The Italian type of first-class boat is 100 ft. long, 11 ft. 8 in. beam, and has a draught of water of 5 ft. 5 in., and 34·5 tons displacement. The cylinders are also somewhat larger, being $13\frac{1}{2}$ and 22 in. diameter, respectively; the boilers are also larger, having a grate surface of 19·4 sq. ft., and a heating surface of 698·8 sq. ft.

The subdivision of the hulls by bulkheads and half-bulkheads is similar to that in the second-class boats, and ejectors are similarly fitted. The six ejectors of the Italian boats are alone capable of pumping out the whole displacement in $7\frac{3}{4}$ minutes. In the Italian boats all the pumps are driven by a separate engine, and the main engines are devoted entirely to propelling the boat.

The English first-class boat carries three 14-in. Whitehead torpedoes, two in transporting carriages on the sides of the vessel, and one in the torpedo gun, as it has been called, on the forward deck. By means of this gun, which can be elevated or trained like an ordinary gun, the torpedo may be projected ahead or on either side. Hence there is no necessity for attacking bows on, as in the second-class boats, or for stopping immediately before or after the discharge. In the earlier examples, the torpedo was ejected by an air-impulse gear; now, a cartridge, containing a slow-burning powder, is used.

The objections to this system are—that the boat carries to the attack only one torpedo ready to be ejected; that the gun cannot be reloaded without retiring, or else exposing the men engaged in the operation to great danger; and the reserve torpedoes are liable to be hit by Nordenfeldt bullets or Hotchkiss shell, either of which would certainly disable them, and might even cause a destructive explosion.

The Italian and Danish boats carry four 14-in. Whitehead torpedoes, arranged as in their second-class boats, that is—two in the ejecting tubes, and two in the loading troughs, immediately behind, but in this case all are completely enveloped in the hull of the boat. To reach them, a bullet would have to penetrate $\frac{3}{32}$ in. of plating, and $\frac{1}{8}$ in. of tube, in all $\frac{7}{32}$ in. The torpedo is ejected by an air-impulse gear, similar to that already described, the air for which and for the torpedoes is supplied at a pressure of 70 atmospheres by a small air-compressing pump in the engine-room.

A permanent lifting gear, similar to that of the second-class boats, has recently been fitted to these boats, and the first two of them, weighing about 28 tons each, were shipped in an hour and a half.

The largest torpedo-boat built by the author's firm, and the largest yet afloat, is that lately supplied to the Danish Government. She is 110 ft. long by 12 ft. beam, draws 6 ft. 3 in. of water, and has a displacement of $52\frac{1}{2}$ tons. Her speed on the three hours' trial was 20 knots per hour, and she carries coal (10 tons) to steam 1,200 knots at a speed of about 11 knots. Her armament consists of four 15-in. Whitehead torpedoes, 19 ft. in length, and carrying a charge of 80 lbs. of gun-cotton. The Danish Government propose to carry this boat and others of her class from point to point of the coast on their railways, so that an enemy would know nothing of their movements or where to expect them.

DIMENSIONS, ARMAMENT, &c., OF TORPEDO-BOATS DESCRIBED IN MR. DONALDSON'S PAPER.

Group	Type	Length (extreme)	Beam	Maximum draught	Displacement	Indicated horse-power	Speed	Torpedo armament	Ejecting apparatus	Machine gun armament	Diameter and weight of projectile	Pumping power in tons per hour	Time required to pump out displacement
		ft. in.	ft. in.	ft. in.	tons		knots						minutes
Second Class	English	60 6	7 6	3 4	10 9	150	17·65	Two 14-in. (Whitehead)	Side frames	None	—	75	$8\frac{1}{2}$
Second Class	English	63 0	7 6	3 4	12 5	150	17·53	„ „	Steam impulse	None	—	75	10
Second Class	Danish and Italian	63 0	7 6	3 4	12 5	150	17·35	„ „	Air impulse	2-barrelled Gardner	$1\frac{1}{2}$ in. diameter	145	$5\frac{1}{4}$
First Class	English	90 6	10 10	4 5	32 5	469	21·76	Three „	Torpedo gun	None	—	147	$13\frac{1}{4}$
First Class	Italian	100 0	11 8	5 5	34 5	446	21·36	Four „	Air impulse	2-barrelled Nordenfeldt	—	270	$7\frac{3}{4}$
First Class	Danish	110 0	12 0	6 3	52 5	750	20·75	Four 15-in.	„ „	5-barrelled Hotchkiss	$1\frac{1}{2}$ in diameter 1 lb. 2 oz. weight	180	$17\frac{1}{2}$

A still larger boat is under construction for the Russian Government; she will be 113 ft. long by 12 ft. 6 in. beam, with a displacement of $58\frac{1}{2}$ tons. Her contract speed is the same as that of the Danish boat, but will be obtained under severer conditions, to secure that the trial trip speed shall be maintained on actual service.

Relatively to the Whitehead torpedo, the Spar torpedo must be considered as a torpedo with a spar 10 yards, as compared with one having a spar 400 yards long, that being the range at which the Whitehead torpedo may be considered tolerably effective. Yet the Spar torpedo is not to be looked on as obsolete, and in the hands of a seafaring population, trained to the use of torpedo-boats, it would prove most efficient. In circumstances such as prevailed at the bombardment of Alexandria, when the attacking ships were so enveloped in smoke that the firing had to be suspended, it is a question whether the Spar torpedo would not have been both the most certain and the least hazardous weapon of attack. The English first-class boats are now being armed with the Spar torpedo as an alternative armament.

In conclusion, the author pointed out the importance of a properly-organised torpedo service for coast defence both at home and in our colonies, and particularly for our scattered coaling stations, which, in the exigencies of a great war, might be left a prey to any adventurous captain. A disaster to our navy, or the calls that might be made upon it in a great war, might leave our harbours and navigable rivers temporarily exposed to the attack of an enemy, and although no one would propose that torpedo boats should take the place of forts and land defences, yet the knowledge of their presence, and the risk of being struck at any moment in his most vulnerable part, would compel an enemy to approach our forts with far greater circumspection than was considered necessary in encountering the heavy guns of the Alexandrian batteries.

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3. *Current Meter Observations in the Tidal Compartment of the Thames. By* Professor W. C. Unwin, *M.I.C.E.*

These observations were made with the object of testing a new form of current meter made by Messrs. Amsler Laffon, of Schaffhausen, and also to examine how far current meter observations could be usefully carried out in a tidal river.

The current meter is a screw current meter, differing from those ordinarily used in the mode of suspension, and in having an electrical signalling arrangement. The meter is carried in gimbals and is free to move in any direction. A long conical rudder keeps the screw normal to the direction of the stream. The meter is suspended in the water by a steel wire with a weight of 40 kilogrammes below it. A small crab or winch for lowering out or raising the meter carries an index, showing the exact depth of the meter from the water surface. The author found the arrangement to work extremely well, the conical rudder appeared to have adequate directing power and the meter held its proper position in the water with very great steadiness. At every 100 rotations of the screw, an electrical circuit is made which rings a bell above water. To obtain the rate of rotation, it is therefore only necessary to note the time of 100 or 200 or 500 revolutions by a chronograph stop-watch. The velocity of the water is obtained from the number of rotations observed, by a suitable formula, with constants determined by previous experiments.

In ordinary river gauging, the difficulty of obtaining accurate results arises, chiefly, from the variations of velocity at each point due to the unsteady motion of the water and the eddies superposed on the general forward motion. In a tidal stream, there is the additional difficulty that the velocity is periodically varying with the continuous change of the depth and surface slope. That observations in a tidal stream should be of any use therefore, it is very necessary that they should be made with considerable rapidity. In the experiments here described the author took entire charge of the current meter, altering its position, noting the time, and recording the revolutions himself. Nevertheless, on the average of six days' work, one velocity was obtained on the average every three minutes, a degree of rapidity very satisfactory.

The observations were all taken on one vertical, in water varying with the phase

of the tide from about 2·2 to 7·3 metres in depth. The observations were taken sometimes at every metre of depth, but more generally at 0·5 metre below the surface, at mid depth, and at 0·2 metre above the bottom. The position of the metre in depth was changed after each observation. Curves were shown giving the velocities near the surface, at mid-depth, and at the bottom during two ebb tides and during a period extending from the end of one ebb, through the period of flow, and into the next period of ebb.

The calculation of the discharge of the river at different periods, and its comparison with the amount of upland water, cannot be given without tables, but the following general facts are interesting.

1. The change in the river-depth at the turn of the tide begins markedly earlier than the change in the direction of flow.

2. The relation of the surface and subsurface velocities is similar to that in a non-tidal river at all periods of ebb and flow.

3. The velocities could not be observed exactly at the turn of the tide, but within a very short period after that instant the bottom water was in motion with a velocity bearing the same relation to the surface velocity as at other periods of the tide.

4. The change of velocity for the half-hour before and after the turn of the tide is extremely rapid.

The observations were made at Putney and Westminster, and the greatest velocities observed were a little less than one metre per second,

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4. *An Apparatus for recording the results of experiments with Railway Brakes.* *By* Sir Frederick Bramwell, *F.R.S.*

This apparatus mainly consists of a train of wheelwork set in motion by a spring, which can be wound up by hand. The motion of the wheelwork causes a continuous strip of paper, of about an inch in width, to travel endways at a regular speed, under a pencil moved alternately to the right and to the left, at right angles to the direction of motion of the paper, the motion of the pencil being produced by connection with an axle of the locomotive drawing the train to which the brakes are attached, a motion of the pencil to the right, and one to the left, being made for each revolution of the axle. It is essential that the axle giving motion to the pencil should neither be driven by the engine nor should its wheels have brakes upon them.

A second pencil is provided, capable of being moved by hand, also at right angles to the direction of motion of the paper. Each of the pencils can be placed in contact with, or removed from, the paper at the will of the operator.

The mode of working is as follows:—

The apparatus being fixed on the locomotive, and the pencil coupled up with the rod of an eccentric placed on the axle, the spring controlling the wheelwork is wound up, and the continuous strip of paper set in motion. Then the pencil is put into contact with the strip of paper, and as the paper moves endways, the pencil makes a series of marks upon it, each of these representing one revolution of the axle, and each representing therefore a forward motion of the locomotive, and of the carriages attached to it, equal to the circumference of the wheels on that axle. The speed at which the paper moves was regulated when the apparatus was constructed, but this speed is ascertained, with absolute accuracy, for each experiment by means of the hand-worked pencil making a second mark upon the paper, and being moved alternately to the right and to the left at any interval of time.

Upon the signal for the shutting off of the steam and the putting on of the brakes being given, a further mark is made by the hand-worked pencil, and this pencil is kept at its then position until the locomotive and the carriages attached to it have come to rest, when a further mark in the opposite direction is made.

Upon considering the diagram thus produced it will be seen that it shows—

1st. The number of revolutions of the driving wheel, and therefore the distance

travelled, and the speed during any given space of time before the brakes are put on.

2nd. The time that has been occupied in bringing the locomotive and the carriages to rest after the brakes are put on; and

3rd. The number of revolutions that have been made by the engine, and therefore the distance travelled during this time.

These are all the necessary elements for recording the efficiency in 'stopping power' of any railway brake. The weight of the locomotive and of the carriages attached to it being known, the speed at which they are travelling when the brakes are put on; the time which it takes to bring them to rest; and the distance over which they travel after the brakes are put on, can all be obtained from the diagram.

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5. *On a combined Gas Motor and Cold Air Machine.* *By* J. J. Colman.

The author described a combination of the refrigerating machine invented by himself with a gas engine of the Otto type, the object being to enable the machine to be used when steam power was not available.

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6. *Collapsible Boats.* *By* E. L. Berthon.

The author described the system invented by himself of collapsible boats, and recommended its adoption in sea-going vessels.

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7. *The Pressure of Wheat stored in Elongated Cells or Bins.* *By* Isaac Roberts, *F.G.S.*

The author gave an account of certain experiments carried out by him with the view of ascertaining the pressure on the bottom of the tall bins in which corn is frequently stored. The result of these experiments showed that, after the corn had reached a certain height in the bin, the weight of any further additions was taken by the sides of the bin and caused no increased pressure on the bottom.

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CONTENTS:—Rev. B. Powell, Report on the Recent Progress of discovery relative to Radiant Heat, supplementary to a former Report on the same subject inserted in the first volume of the Reports of the British Association for the Advancement of Science;—J. D. Forbes, Supplementary Report on Meteorology;—W. S. Harris, Report on Prof. Whewell's Anemometer, now in operation at Plymouth;—Report on 'The Motion and Sounds of the Heart,' by the London Committee of the British Association, for 1839-40;—Prof. Schönbein, an Account of Researches in Electro-Chemistry;—R. Mallet, Second Report upon the Action of Air and Water, whether fresh or salt, clear or foul, and at various temperatures, upon Cast Iron, Wrought Iron, and Steel;—R. W. Fox, Report on some Observations on Subterranean Temperature;—A. F. Osler, Report on the Observations recorded during the years 1837, 1838, 1839, and 1840, by the Self-registering Anemometer erected at the Philosophical Institution, Birmingham;—Sir D. Brewster, Report respecting the Two Series of Hourly Meteorological Observations kept at Inverness and Kingussie, from Nov. 1st, 1838, to Nov. 1st, 1839:—W. Thompson, Report on the Fauna of Ireland: Div. *Verte-*

brata;—C. J. B. Williams, M.D., Report of Experiments on the Physiology of the Lungs and Air-Tubes;—Rev. J. S. Henslow, Report of the Committee on the Preservation of Animal and Vegetable Substances.

Together with the Transactions of the Sections, Mr. Murchison and Major E. Sabine's Address, and Recommendations of the Association and its Committees.

PROCEEDINGS OF THE ELEVENTH MEETING, at Plymouth, 1841, *Published at* 13*s*. 6*d*.

CONTENTS:—Rev. P. Kelland, on the Present State of our Theoretical and Experimental Knowledge of the Laws of Conduction of Heat;—G. L. Roupell, M.D., Report on Poisons;—T. G. Bunt, Report on Discussions of Bristol Tides, under the direction of the Rev. W. Whewell;—D. Ross, Report on the Discussions of Leith Tide Observations, under the direction of the Rev. W. Whewell;—W. S. Harris, upon the working of Whewell's Anemometer at Plymouth during the past year;—Report of a Committee appointed for the purpose of superintending the scientific co-operation of the British Association in the System of Simultaneous Observations in Terrestrial Magnetism and Meteorology;—Reports of Committees appointed to provide Meteorological Instruments for the use of M. Agassiz and Mr. M'Cord;—Report of a Committee appointed to superintend the Reduction of Meteorological Observations;—Report of a Committee for revising the Nomenclature of the Stars;—Report of a Committee for obtaining Instruments and Registers to record Shocks and Earthquakes in Scotland and Ireland;—Report of a Committee on the Preservation of Vegetative Powers in Seeds;—Dr. Hodgkin, on Inquiries into the Races of Man;—Report of the Committee appointed to report how far the Desiderata in our knowledge of the Condition of the Upper Strata of the Atmosphere may be supplied by means of Ascents in Balloons or otherwise, to ascertain the probable expense of such Experiments, and to draw up Directions for Observers in such circumstances;—R. Owen, Report on British Fossil Reptiles;—Reports on the Determination of the Mean Value of Railway Constants;—Dr. D. Lardner, Second and concluding Report on the Determination of the Mean Value of Railway Constants;—E. Woods, Report on Railway Constants;—Report of a Committee on the Construction of a Constant Indicator for Steam Engines.

Together with the Transactions of the Sections, Prof. Whewell's Address, and Recommendations of the Association and its Committees.

PROCEEDINGS OF THE TWELFTH MEETING, at Manchester, 1842, *Published at* 10*s*. 6*d*.

CONTENTS:—Report of the Committee appointed to conduct the co-operation of the British Association in the System of Simultaneous Magnetical and Meteorological Observations;—Dr. J. Richardson, Report on the present State of the Ichthyology of New Zealand;—W. S. Harris, Report on the Progress of Meteorological Observations at Plymouth;—Second Report of a Committee appointed to make Experiments on the Growth and Vitality of Seeds;—C. Vignoles, Report of the Committee on Railway Sections;—Report of the Committee for the Preservation of Animal and Vegetable Substances;—Dr. Lyon Playfair, Abstract of Prof. Liebig's Report on Organic Chemistry applied to Physiology and Pathology;—R. Owen, Report on the British Fossil Mammalia, Part I.;—R. Hunt, Researches on the Influence of Light on the Germination of Seeds and the Growth of Plants;—L. Agassiz, Report on the Fossil Fishes of the Devonian System or Old Red Sandstone;—W. Fairbairn, Appendix to a Report on the Strength and other Properties of Cast Iron obtained from the Hot and Cold Blast;—D. Milne, Report of the Committee for Registering Shocks of Earthquakes in Great Britain;—Report of a Committee on the construction of a Constant Indicator for Steam-Engines, and for the determination of the Velocity of the Piston of the Self-acting Engine at different periods of the Stroke;—J. S. Russell, Report of a Committee on the Form of Ships;—Report of a Committee appointed 'to consider of the Rules by which the Nomenclature of Zoology may be established on a uniform and permanent basis;'—Report of a Committee on the Vital Statistics of Large Towns in Scotland;—Provisional Reports, and Notices of Progress in Special Researches entrusted to Committees and Individuals.

Together with the Transactions of the Sections, Lord Francis Egerton's Address, and Recommendations of the Association and its Committees.

PROCEEDINGS OF THE THIRTEENTH MEETING, at Cork, 1843, *Published at* 12*s*.

CONTENTS:—Robert Mallet, Third Report upon the Action of Air and Water, whether fresh or salt, clear or foul, and at Various Temperatures, upon Cast Iron, Wrought Iron, and Steel;—Report of the Committee appointed to conduct the Co-operation of the British Association in the System of Simultaneous Magnetical and Meteorological Observations;—Sir J. F. W. Herschel, Bart., Report of the Committee appointed for the Reduction of Meteorological Observations;—Report of the Committee appointed for Experiments on Steam-Engines;—Report of the Committee appointed to continue their Experiments on the Vitality of Seeds;—J. S. Russell, Report of a Series of Observations on the Tides of the Frith of Forth and the East Coast of Scotland;—J. S. Russell, Notice of a Report of the Committee on the Form of Ships;—J. Blake, Report on the Physiological Action of Medicines;—Report of the Committee on Zoological Nomenclature;—Report of the Committee for Registering the Shocks of Earthquakes, and making such Meteorological Observations as may appear to them desirable;—Report of the Committee for conducting Experiments with Captive Balloons;—Prof. Wheatstone, Appendix to the Report;—Report of the Committee for the Translation and Publication of Foreign Scientific Memoirs;—C. W. Peach, on the Habits of the Marine Testacea;—E. Forbes, Report on the Mollusca and Radiata of the Ægean Sea, and on their distribution, considered as bearing on Geology;—L. Agassiz, Synoptical Table of British Fossil Fishes, arranged in the order of the Geological Formations;—R. Owen, Report on the British Fossil Mammalia, Part II.;—E. W. Binney, Report on the excavation made at the junction of the Lower New Red Sandstone with the Coal Measures at Collyhurst;—W. Thompson, Report on the Fauna of Ireland: Div. *Invertebrata;*—Provisional Reports, and Notices of Progress in Special Researches entrusted to Committees and Individuals.

Together with the Transactions of the Sections, the Earl of Rosse's Address, and Recommendations of the Association and its Committees.

PROCEEDINGS OF THE FOURTEENTH MEETING, at York, 1844, *Published at* £1.

CONTENTS:—W. B. Carpenter, on the Microscopic Structure of Shells;—J. Alder and A. Hancock, Report on the British Nudibranchiate Mollusca;—R. Hunt, Researches on the Influence of Light on the Germination of Seeds and the Growth of Plants;—Report of a Committee appointed by the British Association in 1840, for revising the Nomenclature of the Stars;—Lt.-Col. Sabine, on the Meteorology of Toronto in Canada;—J. Blackwall, Report on some recent researches into the Structure, Functions, and Economy of the *Araneidea* made in Great Britain;—Earl of Rosse, on the Construction of large Reflecting Telescopes;—Rev. W. V. Harcourt, Report on a Gas-furnace for Experiments on Vitrifaction and other Applications of High Heat in the Laboratory;—Report of the Committee for Registering Earthquake Shocks in Scotland;—Report of a Committee for Experiments on Steam-Engines;—Report of the Committee to investigate the Varieties of the Human Race;—Fourth Report of a Committee appointed to continue their Experiments on the Vitality of Seeds;—W. Fairbairn, on the Consumption of Fuel and the Prevention of Smoke;—F. Ronalds, Report concerning the Observatory of the British Association at Kew;—Sixth Report of the Committee appointed to conduct the Co-operation of the British Association in the System of Simultaneous Magnetical and Meteorological Observations;—Prof. Forchhammer on the influence of Fucoidal Plants upon the Formations of the Earth, on Metamorphism in general, and particularly the Metamorphosis of the Scandinavian Alum Slate;—H. E. Strickland, Report on the Recent Progress and Present State of Ornithology;—T. Oldham, Report of Committee appointed to conduct Observations on Subterranean Temperature in Ireland;—Prof. Owen, Report on the Extinct Mammals of Australia, with descriptions of certain Fossils indicative of the former existence in that continent of large Marsupial Representatives of the Order Pachydermata;—W. S. Harris, Report on the working of Whewell and Osler's Anemometers at Plymouth, for the years 1841, 1842, 1843;—W. R. Birt, Report on Atmospheric Waves;—L. Agassiz, Rapport sur les Poissons Fossiles de l'Argile de Londres, with translation;—J. S.

Russell, Report on Waves;—Provisional Reports, and Notices of Progress in Special Researches entrusted to Committees and Individuals.

Together with the Transactions of the Sections, the Dean of Ely's Address, and Recommendations of the Association and its Committees.

PROCEEDINGS OF THE FIFTEENTH MEETING, at Cambridge, 1845, *Published at* 12*s.*

CONTENTS:—Seventh Report of a Committee appointed to conduct the Co-operation of the British Association in the System of Simultaneous Magnetical and Meteorological Observations;—Lieut.-Col. Sabine, on some Points in the Meteorology of Bombay;—J. Blake, Report on the Physiological Actions of Medicines;—Dr. Von Boguslawski, on the Comet of 1843;—R. Hunt, Report on the Actinograph;—Prof. Schönbein, on Ozone;—Prof. Erman, on the Influence of Friction upon Thermo-Electricity;—Baron Senftenberg, on the Self-registering Meteorological Instruments employed in the Observatory at Senftenberg;—W. R. Birt, Second Report on Atmospheric Waves;—G. R. Porter, on the Progress and Present Extent of Savings' Banks in the United Kingdom;—Prof. Bunsen and Dr. Playfair, Report on the Gases evolved from Iron Furnaces, with reference to the Theory of Smelting of Iron;—Dr. Richardson, Report on the Ichthyology of the Seas of China and Japan;—Report of the Committee on the Registration of Periodical Phenomena of Animals and Vegetables;—Fifth Report of the Committee on the Vitality of Seeds;—Appendix, &c.

Together with the Transactions of the Sections, Sir J. F. W. Herschel's Address, and Recommendations of the Association and its Committees.

PROCEEDINGS OF THE SIXTEENTH MEETING, at Southampton, 1846, *Published at* 15*s.*

CONTENTS:—G. G. Stokes, Report on Recent Researches in Hydrodynamics;—Sixth Report of the Committee on the Vitality of Seeds;—Dr. Schunck, on the Colouring Matters of Madder;—J. Blake, on the Physiological Action of Medicines;—R. Hunt, Report on the Actinograph;—R. Hunt, Notices on the Influence of Light on the Growth of Plants;—R. L. Ellis, on the Recent Progress of Analysis;—Prof. Forchhammer, on Comparative Analytical Researches on Sea Water;—A. Erman, on the Calculation of the Gaussian Constants for 1829;—G. R. Porter, on the Progress, present Amount, and probable future Condition of the Iron Manufacture in Great Britain;—W. R. Birt, Third Report on Atmospheric Waves;—Prof. Owen, Report on the Archetype and Homologies of the Vertebrate Skeleton;—J. Phillips, on Anemometry;—Dr. J. Percy, Report on the Crystalline Flags;—Addenda to Mr. Birt's Report on Atmospheric Waves.

Together with the Transactions of the Sections, Sir R. I. Murchison's Address, and Recommendations of the Association and its Committees.

PROCEEDINGS OF THE SEVENTEENTH MEETING, at Oxford, 1847, *Published at* 18*s.*

CONTENTS:—Prof. Langberg, on the Specific Gravity of Sulphuric Acid at different degrees of dilution, and on the relation which exists between the Development of Heat and the coincident contraction of Volume in Sulphuric Acid when mixed with Water;—R. Hunt, Researches on the Influence of the Solar Rays on the Growth of Plants;—R. Mallet, on the Facts of Earthquake Phenomena;—Prof. Nilsson, on the Primitive Inhabitants of Scandinavia;—W. Hopkins, Report on the Geological Theories of Elevation and Earthquakes;—Dr. W. B. Carpenter, Report on the Microscopic Structure of Shells;—Rev. W. Whewell and Sir James C. Ross, Report upon the Recommendation of an Expedition for the purpose of completing our Knowledge of the Tides;—Dr. Schunck, on Colouring Matters;—Seventh Report of the Committee on the Vitality of Seeds;—J. Glynn, on the Turbine or Horizontal Water-Wheel of France and Germany;—Dr. R. G. Latham, on the present state and

recent progress of Ethnographical Philology;—Dr. J. C. Prichard, on the various methods of Research which contribute to the Advancement of Ethnology, and of the relations of that Science to other branches of Knowledge;—Dr. C. C. J. Bunsen, on the results of the recent Egyptian researches in reference to Asiatic and African Ethnology, and the Classification of Languages;—Dr. C. Meyer, on the Importance of the Study of the Celtic Language as exhibited by the Modern Celtic Dialects still extant;—Dr. Max Müller, on the Relation of the Bengali to the Aryan and Aboriginal Languages of India;—W. R. Birt, Fourth Report on Atmospheric Waves;—Prof. W. H. Dove, Temperature Tables, with Introductory Remarks by Lieut.-Col. E. Sabine;—A. Erman and H. Petersen, Third Report on the Calculation of the Gaussian Constants for 1829.

Together with the Transactions of the Sections, Sir Robert Harry Inglis's Address, and Recommendations of the Association and its Committees.

PROCEEDINGS OF THE EIGHTEENTH MEETING, at Swansea, 1848, *Published at 9s.*

CONTENTS:—Rev. Prof. Powell, A Catalogue of Observations of Luminous Meteors;—J. Glynn, on Water-pressure Engines;—R. A. Smith, on the Air and Water of Towns;—Eighth Report of Committee on the Growth and Vitality of Seeds;—W. R. Birt, Fifth Report on Atmospheric Waves;—E. Schunck, on Colouring Matters;—J. P. Budd, on the advantageous use made of the gaseous escape from the Blast Furnaces at the Ystalyfera Iron Works;—R. Hunt, Report of progress in the investigation of the Action of Carbonic Acid on the Growth of Plants allied to those of the Coal Formations;—Prof. H. W. Dove, Supplement to the Temperature Tables printed in the Report of the British Association for 1847;—Remarks by Prof. Dove on his recently constructed Maps of the Monthly Isothermal Lines of the Globe, and on some of the principal Conclusions in regard to Climatology deducible from them; with an introductory Notice by Lieut.-Col. E. Sabine;—Dr. Daubeny, on the progress of the investigation on the Influence of Carbonic Acid on the Growth of Ferns;—J. Phillips, Notice of further progress in Anemometrical Researches;—Mr. Mallet's Letter to the Assistant-General Secretary;—A. Erman, Second Report on the Gaussian Constants;—Report of a Committee relative to the expediency of recommending the continuance of the Toronto Magnetical and Meteorological Observatory until December 1850.

Together with the Transactions of the Sections, the Marquis of Northampton's Address, and Recommendations of the Association and its Committees.

PROCEEDINGS OF THE NINETEENTH MEETING, at Birmingham, 1849, *Published at 10s.*

CONTENTS:—Rev. Prof. Powell, A Catalogue of Observations of Luminous Meteors;—Earl of Rosse, Notice of Nebulæ lately observed in the Six-feet Reflector;—Prof. Daubeny, on the Influence of Carbonic Acid Gas on the health of Plants, especially of those allied to the Fossil Remains found in the Coal Formation;—Dr. Andrews, Report on the Heat of Combination;—Report of the Committee on the Registration of the Periodic Phenomena of Plants and Animals;—Ninth Report of Committee on Experiments on the Growth and Vitality of Seeds;—F. Ronalds, Report concerning the Observatory of the British Association at Kew, from Aug. 9, 1848 to Sept. 12, 1849;—R. Mallet, Report on the Experimental Inquiry on Railway Bar Corrosion;—W. R. Birt, Report on the Discussion of the Electrical Observations at Kew.

Together with the Transactions of the Sections, the Rev. T. R. Robinson's Address, and Recommendations of the Association and its Committees.

PROCEEDINGS OF THE TWENTIETH MEETING, at Edinburgh, 1850, *Published at 15s.* (Out of Print.)

CONTENTS:—R. Mallet, First Report on the Facts of Earthquake Phenomena;—Rev. Prof. Powell, on Observations of Luminous Meteors;—Dr. T. Williams, on the Structure and History of the British Annelida;—T. C. Hunt, Results of Meteorological Observations taken at St. Michael's from the 1st of January, 1840, to the 31st

of December, 1849;—R. Hunt, on the present State of our Knowledge of the Chemical Action of the Solar Radiations;—Tenth Report of Committee on Experiments on the Growth and Vitality of Seeds;—Major-Gen. Briggs, Report on the Aboriginal Tribes of India;—F. Ronalds, Report concerning the Observatory of the British Association at Kew;—E. Forbes, Report on the Investigation of British Marine Zoology by means of the Dredge;—R. MacAndrew, Notes on the Distribution and Range in depth of Mollusca and other Marine Animals, observed on the coasts of Spain, Portugal, Barbary, Malta, and Southern Italy in 1849;—Prof. Allman, on the Present State of our Knowledge of the Freshwater Polyzoa;—Registration of the Periodical Phenomena of Plants and Animals;—Suggestions to Astronomers for the Observation of the Total Eclipse of the Sun on July 28, 1851.

Together with the Transactions of the Sections, Sir David Brewster's Address, and Recommendations of the Association and its Committees.

PROCEEDINGS OF THE TWENTY-FIRST MEETING, at Ipswich, 1851, *Published at* 16*s.* 6*d.*

CONTENTS:—Rev. Prof. Powell, on Observations of Luminous Meteors;—Eleventh Report of Committee on Experiments on the Growth and Vitality of Seeds;—Dr. J. Drew, on the Climate of Southampton;—Dr. R. A. Smith, on the Air and Water of Towns: Action of Porous Strata, Water, and Organic Matter;—Report of the Committee appointed to consider the probable Effects in an Economical and Physical Point of View of the Destruction of Tropical Forests;—A. Henfrey, on the Reproduction and supposed Existence of Sexual Organs in the Higher Cryptogamous Plants;—Dr. Daubeny, on the Nomenclature of Organic Compounds;—Rev. Dr. Donaldson, on two unsolved Problems in Indo-German Philology; —Dr. T. Williams, Report on the British Annelida;—R. Mallet, Second Report on the Facts of Earthquake Phenomena;—Letter from Prof. Henry to Col. Sabine, on the System of Meteorological Observations proposed to be established in the United States;—Col. Sabine, Report on the Kew Magnetographs;—J. Welsh, Report on the Performance of his three Magnetographs during the Experimental Trial at the Kew Observatory;—F. Ronalds, Report concerning the Observatory of the British Association at Kew, from September 12, 1850, to July 31, 1851;—Ordnance Survey of Scotland.

Together with the Transactions of the Sections, Prof. Airy's Address, and Recommendations of the Association and its Committees.

PROCEEDINGS OF THE TWENTY-SECOND MEETING, at Belfast, 1852, *Published at* 15*s.*

CONTENTS:—R. Mallet, Third Report on the Facts of Earthquake Phenomena;—Twelfth Report of Committee on Experiments on the Growth and Vitality of Seeds; —Rev. Prof. Powell, Report on Observations of Luminous Meteors, 1851-52;—Dr. Gladstone, on the Influence of the Solar Radiations on the Vital Powers of Plants; —A Manual of Ethnological Inquiry;—Col. Sykes, Mean Temperature of the Day, and Monthly Fall of Rain at 127 Stations under the Bengal Presidency;—Prof. J. D. Forbes, on Experiments on the Laws of the Conduction of Heat;—R. Hunt, on the Chemical Action of the Solar Radiations;—Dr. Hodges, on the Composition and Economy of the Flax Plant;—W. Thompson, on the Freshwater Fishes of Ulster;—W. Thompson, Supplementary Report on the Fauna of Ireland;—W. Wills, on the Meteorology of Birmingham;—J. Thomson, on the Vortex-Water-Wheel;—J. B. Lawes and Dr. Gilbert, on the Composition of Foods in relation to Respiration and the Feeding of Animals.

Together with the Transactions of the Sections, Colonel Sabine's Address, and Recommendations of the Association and its Committees.

PROCEEDINGS OF THE TWENTY-THIRD MEETING, at Hull, 1853, *Published at* 10*s.* 6*d.*

CONTENTS:—Rev. Prof. Powell, Report on Observations of Luminous Meteors, 1852–53;—James Oldham, on the Physical Features of the Humber;—James Oldham, on the Rise, Progress, and Present Position of Steam Navigation in Hull;—

William Fairbairn, Experimental Researches to determine the Strength of Locomotive Boilers, and the causes which lead to Explosion;—J. J. Sylvester, Provisional Report on the Theory of Determinants;—Professor Hodges, M.D., Report on the Gases evolved in Steeping Flax, and on the Composition and Economy of the Flax Plant;—Thirteenth Report of Committee on Experiments on the Growth and Vitality of Seeds;—Robert Hunt, on the Chemical Action of the Solar Radiations; —Dr. John P. Bell, Observations on the Character and Measurements of Degradation of the Yorkshire Coast;—First Report of Committee on the Physical Character of the Moon's Surface, as compared with that of the Earth;—R. Mallet, Provisional Report on Earthquake Wave-Transits; and on Seismometrical Instruments;—William Fairbairn, on the Mechanical Properties of Metals as derived from repeated Meltings, exhibiting the maximum point of strength and the causes of deterioration; —Robert Mallet, Third Report on the Facts of Earthquake Phenomena (continued).

Together with the Transactions of the Sections, Mr. Hopkins's Address, and Recommendations of the Association and its Committees.

PROCEEDINGS OF THE TWENTY-FOURTH MEETING, at Liverpool, 1854, *Published at* 18*s.*

CONTENTS:—R. Mallet, Third Report on the Facts of Earthquake Phenomena (continued);—Major-General Chesney, on the Construction and General Use of Efficient Life-Boats;—Rev. Prof. Powell, Third Report on the present State of our Knowledge of Radiant Heat;—Colonel Sabine, on some of the results obtained at the British Colonial Magnetic Observatories;—Colonel Portlock, Report of the Committee on Earthquakes, with their proceedings respecting Seismometers;—Dr. Gladstone, on the Influence of the Solar Radiations on the Vital Powers of Plants, Part 2;—Rev. Prof. Powell, Report on Observations of Luminous Meteors, 1853–54; —Second Report of the Committee on the Physical Character of the Moon's Surface; —W. G. Armstrong, on the Application of Water-Pressure Machinery;—J. B. Lawes and Dr. Gilbert, on the Equivalency of Starch and Sugar in Food;—Archibald Smith, on the Deviations of the Compass in Wooden and Iron Ships;—Fourteenth Report of Committee on Experiments on the Growth and Vitality of Seeds.

Together with the Transactions of the Sections, the Earl of Harrowby's Address, and Recommendations of the Association and its Committees.

PROCEEDINGS OF THE TWENTY-FIFTH MEETING, at Glasgow, 1855, *Published at* 15*s.*

CONTENTS:—T. Dobson, Report on the Relation between Explosions in Coal-Mines and Revolving Storms;—Dr. Gladstone, on the Influence of the Solar Radiations on the Vital Powers of Plants growing under different Atmospheric Conditions, Part 3;—C. Spence Bate, on the British Edriophthalma;—J. F. Bateman, on the present state of our knowledge on the Supply of Water to Towns;—Fifteenth Report of Committee on Experiments on the Growth and Vitality of Seeds;—Rev. Prof. Powell, Report on Observations of Luminous Meteors, 1854–55;—Report of Committee appointed to inquire into the best means of ascertaining those properties of Metals and effects of various modes of treating them which are of importance to the durability and efficiency of Artillery;—Rev. Prof. Henslow, Report on Typical Objects in Natural History;—A. Follett Osler, Account of the Self-registering Anemometer and Rain-Gauge at the Liverpool Observatory;—Provisional Reports.

Together with the Transactions of the Sections, the Duke of Argyll's Address, and Recommendations of the Association and its Committees.

PROCEEDINGS OF THE TWENTY-SIXTH MEETING, at Cheltenham, 1856, *Published at* 18*s.*

CONTENTS:—Report from the Committee appointed to investigate and report upon the effects produced upon the Channels of the Mersey by the alterations which within the last fifty years have been made in its Banks;—J. Thomson, Interim Report on progress in Researches on the Measurement of Water by Weir Boards;—Dredging Report, Frith of Clyde, 1856;—Rev. B. Powell, Report on Observations of Luminous Meteors, 1855–1856;—Prof. Bunsen and Dr. H. E. Roscoe, Photochemical Researches;—Rev. James Booth, on the Trigonometry of the Parabola, and the

Geometrical Origin of Logarithms;—R. MacAndrew, Report on the Marine Testaceous Mollusca of the North-east Atlantic and neighbouring Seas, and the physical conditions affecting their development;—P. P. Carpenter, Report on the present state of our knowledge with regard to the Mollusca of the West Coast of North America;—T. C. Eyton, Abstract of First Report on the Oyster Beds and Oysters of the British Shores;—Prof. Phillips, Report on Cleavage, and Foliation in Rocks, and on the Theoretical Explanations of these Phenomena, Part 1;—Dr. T. Wright, on the Stratigraphical Distribution of the Oolitic Echinodermata;—W. Fairbairn, on the Tensile Strength of Wrought Iron at various Temperatures;—C. Atherton, on Mercantile Steam Transport Economy;—J. S. Bowerbank, on the Vital Powers of the Spongiadæ;—Report of a Committee upon the Experiments conducted at Stormontfield, near Perth, for the artificial propagation of Salmon;—Provisional Report on the Measurement of Ships for Tonnage;—On Typical Forms of Minerals, Plants and Animals for Museums;—J. Thomson, Interim Report on Progress in Researches on the Measurement of Water by Weir Boards;—R. Mallet, on Observations with the Seismometer;—A. Cayley, on the Progress of Theoretical Dynamics;—Report of a Committee appointed to consider the formation of a Catalogue of Philosophical Memoirs.

Together with the Transactions of the Sections, Dr. Daubeny's Address, and Recommendations of the Association and its Committees.

PROCEEDINGS OF THE TWENTY-SEVENTH MEETING, at Dublin, 1857, *Published at* 15*s*.

CONTENTS:—A. Cayley, Report on the recent progress of Theoretical Dynamics;—Sixteenth and Final Report of Committee on Experiments on the Growth and Vitality of Seeds;—James Oldham, C.E., continuation of Report on Steam Navigation at Hull;—Report of a Committee on the Defects of the present methods of Measuring and Registering the Tonnage of Shipping, as also of Marine Engine-Power, and to frame more perfect rules, in order that a correct and uniform principle may be adopted to estimate the Actual Carrying Capabilities and Working-power of Steam Ships;—Robert Were Fox, Report on the Temperature of some Deep Mines in Cornwall;—Dr. G. Plarr, de quelques Transformations de la Somme $\Sigma_0^{t}{}^{-a} \frac{a^{t|+1}\beta^{t|+1}\delta^{t|+1}}{1^{t|+1}\gamma^{t|+1}\epsilon^{t|+1}}$ a étant entier négatif, et de quelques cas dans lesquels cette somme est exprimable par une combinaison de factorielles, la notation $a^{t|+1}$ désignant le produit des facteurs $a\ (a+1)\ (a+2)$ &c.... $(a+t-1)$;—G. Dickie, M.D., Report on the Marine Zoology of Strangford Lough, County Down, and corresponding part of the Irish Channel;—Charles Atherton, Suggestions for Statistical Inquiry into the Extent to which Mercantile Steam Transport Economy is affected by the Constructive Type of Shipping, as respects the Proportions of Length, Breadth, and Depth;—J. S. Bowerbank, Further Report on the Vitality of the Spongiadæ;—Dr. John P. Hodges, on Flax;—Major-General Sabine, Report of the Committee on the Magnetic Survey of Great Britain;—Rev. Baden Powell, Report on Observations of Luminous Meteors, 1856-57;—C. Vignoles, on the Adaptation of Suspension Bridges to sustain the passage of Railway Trains;—Prof. W. A. Miller, on Electro-Chemistry;—John Simpson, Results of Thermometrical Observations made at the *Plover's* Wintering-place, Point Barrow, latitude 71° 21′ N., long. 156° 17′ W., in 1852-54;—Charles James Hargreave, on the Algebraic Couple; and on the Equivalents of Indeterminate Expressions;—Thomas Grubb, Report on the Improvement of Telescope and Equatorial Mountings;—Prof. James Buckman, Report on the Experimental Plots in the Botanical Garden of the Royal Agricultural College at Cirencester;—William Fairbairn, on the Resistance of Tubes to Collapse;—George C. Hyndman, Report of the Proceedings of the Belfast Dredging Committee;—Peter W. Barlow, on the Mechanical Effect of combining Girders and Suspension Chains, and a Comparison of the Weight of Metal in Ordinary and Suspension Girders, to produce equal deflections with a given load;—J. Park Harrison, Evidences of Lunar Influence on Temperature;—Report on the Animal and Vegetable Products imported into Liverpool from the year 1851 to 1855 (inclusive);—Andrew Henderson, Report on the Statistics of Life-boats and Fishing-boats on the Coasts of the United Kingdom.

Together with the Transactions of the Sections, the Rev. H. Lloyd's Address, and Recommendations of the Association and its Committees.

PROCEEDINGS OF THE TWENTY-EIGHTH MEETING, at Leeds, September 1858, *Published at* 20*s*.

CONTENTS:—R. Mallet, Fourth Report upon the Facts and Theory of Earthquake Phenomena;—Rev. Prof. Powell, Report on Observations of Luminous Meteors, 1857, 1858;—R. H. Meade, on some Points in the Anatomy of the Araneidea or true Spiders, especially on the internal structure of their Spinning Organs;—W. Fairbairn, Report of the Committee on the Patent Laws;—S. Eddy, on the Lead Mining Districts of Yorkshire;—W. Fairbairn, on the Collapse of Glass Globes and Cylinders;—Dr. E. Perceval Wright and Prof. J. Reay Greene, Report on the Marine Fauna of the South and West Coasts of Ireland;—Prof. J. Thomson, on Experiments on the Measurement of Water by Triangular Notches in Weir Boards;—Major-General Sabine, Report of the Committee on the Magnetic Survey of Great Britain;—Michael Connel and William Keddie, Report on Animal, Vegetable, and Mineral Substances imported from Foreign Countries into the Clyde (including the Ports of Glasgow, Greenock, and Port Glasgow) in the years 1853, 1854, 1855, 1856, and 1857;—Report of the Committee on Shipping Statistics;—Rev. H. Lloyd, D.D., Notice of the Instruments employed in the Magnetic Survey of Ireland, with some of the Results;—Prof. J. R. Kinahan, Report of Dublin Dredging Committee, appointed 1857–58;—Prof. J. R. Kinahan, Report on Crustacea of Dublin District;—Andrew Henderson, on River Steamers, their Form, Construction, and Fittings, with reference to the necessity for improving the present means of Shallow-Water Navigation on the Rivers of British India;—George C. Hyndman, Report of the Belfast Dredging Committee;—Appendix to Mr. Vignoles' Paper 'On the Adaptation of Suspension Bridges to sustain the passage of Railway Trains;'—Report of the Joint Committee of the Royal Society and the British Association, for procuring a continuance of the Magnetic and Meteorological Observatories;—R. Beckley, Description of a Self-recording Anemometer.

Together with the Transactions of the Sections, Prof. Owen's Address, and Recommendations of the Association and its Committees.

PROCEEDINGS OF THE TWENTY-NINTH MEETING, at Aberdeen, September 1859, *Published at* 15*s*.

CONTENTS:—George C. Foster, Preliminary Report on the Recent Progress and Present State of Organic Chemistry;—Professor Buckman, Report on the Growth of Plants in the Garden of the Royal Agricultural College, Cirencester;—Dr. A. Voelcker, Report on Field Experiments and Laboratory Researches on the Constituents of Manures essential to Cultivated Crops;—A. Thomson, of Banchory, Report on the Aberdeen Industrial Feeding Schools;—On the Upper Silurians of Lesmahagow, Lanarkshire;—Alphonse Gages, Report on the Results obtained by the Mechanico-Chemical Examination of Rocks and Minerals;—William Fairbairn, Experiments to determine the Efficiency of Continuous and Self-acting Breaks for Railway Trains;—Professor J. R. Kinahan, Report of Dublin Bay Dredging Committee for 1858–59;—Rev. Baden Powell, Report on Observations of Luminous Meteors for 1858–59;—Professor Owen, Report on a Series of Skulls of various Tribes of Mankind inhabiting Nepal, collected, and presented to the British Museum, by Bryan H. Hodgson, Esq., late Resident in Nepal, &c., &c.;—Messrs. Maskelyne, Hadow, Hardwich, and Llewelyn, Report on the Present State of our Knowledge regarding the Photographic Image;—G. C. Hyndman, Report of the Belfast Dredging Committee for 1859;—James Oldham, Continuation of Report of the Progress of Steam Navigation at Hull;—Charles Atherton, Mercantile Steam Transport Economy as affected by the Consumption of Coals;—Warren De La Rue, Report on the present state of Celestial Photography in England;—Professor Owen, on the Orders of Fossil and Recent Reptilia, and their Distribution in Time;—Balfour Stewart, on some Results of the Magnetic Survey of Scotland in the years 1857 and 1858, undertaken, at the request of the British Association, by the late John Welsh, Esq., F.R.S.;—W. Fairbairn, The Patent Laws: Report of Committee on the Patent Laws;—J. Park Harrison, Lunar Influence on the Temperature of the Air:—Balfour Stewart, an Account of the Construction of the Self-recording Magnetographs at present in operation at the Kew Observatory of the British Association;—Professor H. J. Stephen Smith, Report on the Theory of Numbers, Part I.;—Report of the Committee on Steamship Performance;—Report of the Proceedings of the Balloon Committee of the British Association

appointed at the Meeting at Leeds;—Prof. William K. Sullivan, Preliminary Report on the Solubility of Salts at Temperatures above 100° Cent., and on the Mutual Action of Salts in Solution.

Together with the Transactions of the Sections, Prince Albert's Address, and Recommendations of the Association and its Committees.

PROCEEDINGS OF THE THIRTIETH MEETING, at Oxford, June and July 1860, *Published at* 15*s.*

CONTENTS:—James Glaisher, Report on Observations of Luminous Meteors, 1859-60;—J. R. Kinahan, Report of Dublin Bay Dredging Committee;—Rev. J. Anderson, Report on the Excavations in Dura Den;—Prof. Buckman, Report on the Experimental Plots in the Botanical Garden of the Royal Agricultural College, Cirencester;—Rev. R. Walker, Report of the Committee on Balloon Ascents;—Prof. W. Thomson, Report of Committee appointed to prepare a Self-recording Atmospheric Electrometer for Kew, and Portable Apparatus for observing Atmospheric Electricity;—William Fairbairn, Experiments to determine the Effect of Vibratory Action and long-continued Changes of Load upon Wrought-iron Girders;—R. P. Greg, Catalogue of Meteorites and Fireballs, from A.D. 2 to A.D. 1860;—Prof. H. J. S. Smith, Report on the Theory of Numbers, Part II.;—Vice-Admiral Moorsom, on the Performance of Steam-vessels, the Functions of the Screw, and the Relations of its Diameter and Pitch to the Form of the Vessel;—Rev. W. V. Harcourt, Report on the Effects of long-continued Heat, illustrative of Geological Phenomena;—Second Report of the Committee on Steamship Performance;—Interim Report on the Gauging of Water by Triangular Notches;—List of the British Marine Invertebrate Fauna.

Together with the Transactions of the Sections, Lord Wrottesley's Address, and Recommendations of the Association and its Committees.

PROCEEDINGS OF THE THIRTY-FIRST MEETING, at Manchester, September 1861, *Published at* £1.

CONTENTS:—James Glaisher, Report on Observations of Luminous Meteors;—Dr. E. Smith, Report on the Action of Prison Diet and Discipline on the Bodily Functions of Prisoners, Part I.;—Charles Atherton, on Freight as affected by Differences in the Dynamic Properties of Steamships;—Warren De La Rue, Report on the Progress of Celestial Photography since the Aberdeen Meeting;—B. Stewart, on the Theory of Exchanges, and its recent extension;—Drs. E. Schunck, R. Angus Smith, and H. E. Roscoe, on the Recent Progress and Present Condition of Manufacturing Chemistry in the South Lancashire District;—Dr. J. Hunt, on Ethno-Climatology; or, the Acclimatization of Man;—Prof. J. Thomson, on Experiments on the Gauging of Water by Triangular Notches;—Dr. A. Voelcker, Report on Field Experiments and Laboratory Researches on the Constituents of Manures essential to cultivated Crops;—Prof. H. Hennessy, Provisional Report on the Present State of our Knowledge respecting the Transmission of Sound-signals during Fogs at Sea;—Dr. P. L. Sclater and F. von Hochstetter, Report on the Present State of our Knowledge of the Birds of the Genus *Apteryx* living in New Zealand;—J. G. Jeffreys, Report of the Results of Deep-sea Dredging in Zetland, with a Notice of several Species of Mollusca new to Science or to the British Isles;—Prof. J. Phillips, Contributions to a Report on the Physical Aspect of the Moon;—W. R. Birt, Contribution to a Report on the Physical Aspect of the Moon;—Dr. Collingwood and Mr. Byerley, Preliminary Report of the Dredging Committee of the Mersey and Dee;—Third Report of the Committee on Steamship Performance;—J. G. Jeffreys, Preliminary Report on the Best Mode of preventing the Ravages of *Teredo* and other Animals in our Ships and Harbours;—R. Mallet, Report on the Experiments made at Holyhead to ascertain the Transit-Velocity of Waves, analogous to Earthquake Waves, through the local Rock Formations;—T. Dobson, on the Explosions in British Coal-Mines during the year 1859;—J. Oldham, Continuation of Report on Steam Navigation at Hull;—Prof. G. Dickie, Brief Summary of a Report on the Flora of the North of Ireland;—Prof. Owen, on the Psychical and Physical Characters of the Mincopies, or Natives of the Andaman Islands, and on the Relations thereby indicated to other Races of Mankind;—Colonel Sykes, Report of the Balloon Committee;—Major-General Sabine, Report on the Repetition of the Magnetic Survey of England;—Interim Report of the Committee for

Dredging on the North and East Coasts of Scotland;—W. Fairbairn, on the Resistance of Iron Plates to Statical Pressure and the Force of Impact by Projectiles at High Velocities;—W. Fairbairn, Continuation of Report to determine the effect of Vibratory Action and long-continued Changes of Load upon Wrought-Iron Girders; —Report of the Committee on the Law of Patents;—Prof. H. J. S. Smith, Report on the Theory of Numbers, Part III.

Together with the Transactions of the Sections, Mr. Fairbairn's Address, and Recommendations of the Association and its Committees.

PROCEEDINGS OF THE THIRTY-SECOND MEETING at Cambridge, October 1862, *Published at £1.*

CONTENTS:—James Glaisher, Report on Observations of Luminous Meteors, 1861–62;—G. B. Airy, on the Strains in the Interior of Beams;—Archibald Smith and F. J. Evans, Report on the three Reports of the Liverpool Compass Committee;—Report on Tidal Observations on the Humber;—T. Aston, on Rifled Guns and Projectiles adapted for Attacking Armour-plate Defences;—Extracts, relating to the Observatory at Kew, from a Report presented to the Portuguese Government, by Dr. J. A. de Souza;—H. T. Mennell, Report on the Dredging of the Northumberland Coast and Dogger Bank;—Dr. Cuthbert Collingwood, Report upon the best means of advancing Science through the agency of the Mercantile Marine;—Messrs. Williamson, Wheatstone, Thomson, Miller, Matthiessen, and Jenkin, Provisional Report on Standards of Electrical Resistance;—Preliminary Report of the Committee for investigating the Chemical and Mineralogical Composition of the Granites of Donegal;—Prof. H. Hennessy, on the Vertical Movements of the Atmosphere considered in connection with Storms and Changes of Weather;—Report of Committee on the application of Gauss's General Theory of Terrestrial Magnetism to the Magnetic Variations;—Fleeming Jenkin, on Thermo-electric Currents in Circuits of one Metal;—W. Fairbairn, on the Mechanical Properties of Iron Projectiles at High Velocities;—A. Cayley, Report on the Progress of the Solution of certain Special Problems of Dynamics; —Prof. G. G. Stokes, Report on Double Refraction;—Fourth Report of the Committee on Steamship Performance;—G. J. Symons, on the Fall of Rain in the British Isles in 1860 and 1861;—J. Ball, on Thermometric Observations in the Alps;—J. G. Jeffreys, Report of the Committee for Dredging on the North and East Coasts of Scotland;—Report of the Committee on Technical and Scientific Evidence in Courts of Law;—James Glaisher, Account of Eight Balloon Ascents in 1862;—Prof. H. J. S. Smith, Report on the Theory of Numbers, Part IV.

Together with the Transactions of the Sections, the Rev. Prof. R. Willis's Address and Recommendations of the Association and its Committees.

PROCEEDINGS OF THE THIRTY-THIRD MEETING, at Newcastle-upon-Tyne, August and September 1863, *Published at £1 5s.*

CONTENTS:—Report of the Committee on the Application of Gun-cotton to Warlike Purposes;—A. Matthiessen, Report on the Chemical Nature of Alloys;—Report of the Committee on the Chemical and Mineralogical Constitution of the Granites of Donegal, and on the Rocks associated with them;—J. G. Jeffreys, Report of the Committee appointed for exploring the Coasts of Shetland by means of the Dredge;—G. D. Gibb, Report on the Physiological Effects of the Bromide of Ammonium;—C. K. Aken, on the Transmutation of Spectral Rays, Part I.;—Dr. Robinson, Report of the Committee on Fog Signals;—Report of the Committee on Standards of Electrical Resistance;—E. Smith, Abstract of Report by the Indian Government on the Foods used by the Free and Jail Populations in India;—A. Gages, Synthetical Researches on the Formation of Minerals, &c.;—R. Mallet, Preliminary Report on the Experimental Determination of the Temperatures of Volcanic Foci, and of the Temperature, State of Saturation, and Velocity of the issuing Gases and Vapours;—Report of the Committee on Observations of Luminous Meteors;—Fifth Report of the Committee on Steamship Performance;—G. J. Allman, Report on the Present State of our Knowledge of the Reproductive System in the Hydroida;—J. Glaisher, Account of Five Balloon Ascents made in 1863;—P. P. Carpenter, Supplementary Report on the Present State of our Knowledge with regard to the Mollusca of the West Coast of North America;—Prof. Airy, Report on Steam Boiler Explosions;—C. W. Siemens, Obser-

vations on the Electrical Resistance and Electrification of some Insulating Materials under Pressures up to 300 Atmospheres;—C. M. Palmer, on the Construction of Iron Ships and the Progress of Iron Shipbuilding on the Tyne, Wear, and Tees;—Messrs. Richardson, Stevenson, and Clapham, on the Chemical Manufactures of the Northern Districts;—Messrs. Sopwith and Richardson, on the Local Manufacture of Lead, Copper, Zinc, Antimony, &c.;—Messrs. Daglish and Forster, on the Magnesian Limestone of Durham;—I. L. Bell, on the Manufacture of Iron in connexion with the Northumberland and Durham Coal-field;—T. Spencer, on the Manufacture of Steel in the Northern District;—Prof. H. J. S. Smith, Report on the Theory of Numbers, Part V.

Together with the Transactions of the Sections, Sir William Armstrong's Address, and Recommendations of the Association and its Committees.

PROCEEDINGS OF THE THIRTY-FOURTH MEETING, at Bath, September 1864, *Published at* 18*s*.

CONTENTS:—Report of the Committee for Observations of Luminous Meteors;—Report of the Committee on the best means of providing for a Uniformity of Weights and Measures;—T. S. Cobbold, Report of Experiments respecting the Development and Migration of the Entozoa;—B. W. Richardson, Report on the Physiological Action of Nitrite of Amyl;—J. Oldham, Report of the Committee on Tidal Observations;—G. S. Brady, Report on Deep-sea Dredging on the Coasts of Northumberland and Durham in 1864;—J. Glaisher, Account of Nine Balloon Ascents made in 1863 and 1864;—J. G. Jeffreys, Further Report on Shetland Dredgings;—Report of the Committee on the Distribution of the Organic Remains of the North Staffordshire Coal-field;—Report of the Committee on Standards of Electrical Resistance;—G. J. Symons, on the Fall of Rain in the British Isles in 1862 and 1863;—W. Fairbairn, Preliminary Investigation of the Mechanical Properties of the proposed Atlantic Cable.

Together with the Transactions of the Sections, Sir Charles Lyell's Address, and Recommendations of the Association and its Committees.

PROCEEDINGS OF THE THIRTY-FIFTH MEETING, at Birmingham, September 1865, *Published at* £1 5*s*.

CONTENTS:—J. G. Jeffreys, Report on Dredging among the Channel Isles;—F. Buckland, Report on the Cultivation of Oysters by Natural and Artificial Methods;—Report of the Committee for exploring Kent's Cavern;—Report of the Committee on Zoological Nomenclature;—Report on the Distribution of the Organic Remains of the North Staffordshire Coal-field;—Report on the Marine Fauna and Flora of the South Coast of Devon and Cornwall;—Interim Report on the Resistance of Water to Floating and Immersed Bodies;—Report on Observations of Luminous Meteors;—Report on Dredging on the Coast of Aberdeenshire;—J. Glaisher, Account of Three Balloon Ascents;—Interim Report on the Transmission of Sound under Water;—G. J. Symons, on the Rainfall of the British Isles;—W. Fairbairn, on the Strength of Materials considered in relation to the Construction of Iron Ships;—Report of the Gun-Cotton Committee;—A. F. Osler, on the Horary and Diurnal Variations in the Direction and Motion of the Air at Wrottesley, Liverpool, and Birmingham;—B. W. Richardson, Second Report on the Physiological Action of certain of the Amyl Compounds;—Report on further Researches in the Lingula-flags of South Wales;—Report of the Lunar Committee for Mapping the Surface of the Moon;—Report on Standards of Electrical Resistance;—Report of the Committee appointed to communicate with the Russian Government respecting Magnetical Observations at Tiflis;—Appendix to Report on the Distribution of the Vertebrate Remains from the North Staffordshire Coal-field;—H. Woodward, First Report on the Structure and Classification of the Fossil Crustacea;—Prof. H. J. S. Smith, Report on the Theory of Numbers, Part VI.;—Report on the best means of providing for a Uniformity of Weights and Measures, with reference to the interests of Science;—A. G. Findlay, on the Bed of the Ocean;—Prof. A. W. Williamson, on the Composition of Gases evolved by the Bath Spring called King's Bath.

Together with the Transactions of the Sections, Prof. Phillips's Address, and Recommendations of the Association and its Committees.

PROCEEDINGS OF THE THIRTY-SIXTH MEETING, at Nottingham, August 1866, *Published at £1 4s.*

CONTENTS:—Second Report on Kent's Cavern, Devonshire;—A. Matthiessen, Preliminary Report on the Chemical Nature of Cast Iron;—Report on Observations of Luminous Meteors;—W. S. Mitchell, Report on the Alum Bay Leaf-bed;—Report on the Resistance of Water to Floating and Immersed Bodies;—Dr. Norris, Report on Muscular Irritability;—Dr. Richardson, Report on the Physiological Action of certain compounds of Amyl and Ethyl;—H. Woodward, Second Report on the Structure and Classification of the Fossil Crustacea;—Second Report on the 'Menevian Group,' and the other Formations at St. David's, Pembrokeshire;—J. G. Jeffreys, Report on Dredging among the Hebrides;—Rev. A. M. Norman, Report on the Coasts of the Hebrides, Part II.;—J. Alder, Notices of some Invertebrata, in connexion with Mr. Jeffreys's Report;—G. S. Brady, Report on the *Ostracoda* dredged amongst the Hebrides;—Report on Dredging in the Moray Firth;—Report on the Transmission of Sound-Signals under Water;—Report of the Lunar Committee;—Report of the Rainfall Committee;—Report on the best means of providing for a Uniformity of Weights and Measures, with reference to the Interests of Science;—J. Glaisher, Account of Three Balloon Ascents;—Report on the Extinct Birds of the Mascarene Islands;—Report on the Penetration of Ironclad Ships by Steel Shot;—J. A. Wanklyn, Report on Isomerism among the Alcohols;—Report on Scientific Evidence in Courts of Law;—A. L. Adams, Second Report on Maltese Fossiliferous Caves, &c.

Together with the Transactions of the Sections, Mr. Grove's Address, and Recommendations of the Association and its Committees.

PROCEEDINGS OF THE THIRTY-SEVENTH MEETING, at Dundee, September 1867, *Published at £1 6s.*

CONTENTS:—Report of the Committee for Mapping the Surface of the Moon;—Third Report on Kent's Cavern, Devonshire;—On the present State of the Manufacture of Iron in Great Britain;—Third Report on the Structure and Classification of the Fossil Crustacea;—Report on the Physiological Action of the Methyl Compounds;—Preliminary Report on the Exploration of the Plant-Beds of North Greenland;—Report of the Steamship Performance Committee;—On the Meteorology of Port Louis, in the Island of Mauritius;—On the Construction and Works of the Highland Railway;—Experimental Researches on the Mechanical Properties of Steel;—Report on the Marine Fauna and Flora of the South Coast of Devon and Cornwall;—Supplement to a Report on the Extinct Didine Birds of the Mascarene Islands;—Report on Observations of Luminous Meteors;—Fourth Report on Dredging among the Shetland Isles;—Preliminary Report on the Crustacea, &c., procured by the Shetland Dredging Committee in 1867;—Report on the Foraminifera obtained in the Shetland Seas;—Second Report of the Rainfall Committee;—Report on the best means of providing for a Uniformity of Weights and Measures, with reference to the interests of Science;—Report on Standards of Electrical Resistance.

Together with the Transactions of the Sections, and Recommendations of the Association and its Committees.

PROCEEDINGS OF THE THIRTY-EIGHTH MEETING, at Norwich, August 1868, *Published at £1 5s.*

CONTENTS:—Report of the Lunar Committee;—Fourth Report on Kent's Cavern, Devonshire;—On Puddling Iron;—Fourth Report on the Structure and Classification of the Fossil Crustacea;—Report on British Fossil Corals;—Report on Spectroscopic Investigations of Animal Substances;—Report of Steamship Performance Committee;—Spectrum Analysis of the Heavenly Bodies;—On Stellar Spectrometry;—Report on the Physiological Action of the Methyl and allied Compounds;—Report on the Action of Mercury on the Biliary Secretion;—Last Report on Dredging among the Shetland Isles;—Reports on the Crustacea, &c., and on the Annelida and Foraminifera from the Shetland Dredgings;—Report on the Chemical Nature of Cast Iron, Part I.;—Interim Report on the Safety of Merchant Ships and their Passengers;—Report on Observations of Luminous Meteors;—Preliminary Report

on Mineral Veins containing Organic Remains;—Report on the Desirability of Explorations between India and China;—Report of Rainfall Committee;—Report on Synthetical Researches on Organic Acids;—Report on Uniformity of Weights and Measures;—Report of the Committee on Tidal Observations;—Report of the Committee on Underground Temperature;—Changes of the Moon's Surface;—Report on Polyatomic Cyanides.

Together with the Transactions of the Sections, Dr. Hooker's Address, and Recommendations of the Association and its Committees.

PROCEEDINGS OF THE THIRTY-NINTH MEETING, at Exeter, August 1869, *Published at* £1 2*s*.

CONTENTS:—Report on the Plant-beds of North Greenland;—Report on the existing knowledge on the Stability, Propulsion, and Sea-going qualities of Ships; —Report on Steam-boiler Explosions;—Preliminary Report on the Determination of the Gases existing in Solution in Well-waters;—The Pressure of Taxation on Real Property;—On the Chemical Reactions of Light discovered by Prof. Tyndall;—On Fossils obtained at Kiltorkan Quarry, co. Kilkenny;—Report of the Lunar Committee;—Report on the Chemical Nature of Cast Iron;—Report on the Marine Fauna and Flora of the South Coast of Devon and Cornwall;—Report on the Practicability of establishing a 'Close Time' for the Protection of Indigenous Animals;—Experimental Researches on the Mechanical Properties of Steel;—Second Report on British Fossil Corals;—Report of the Committee appointed to get cut and prepared Sections of Mountain-Limestone Corals for Photographing;—Report on the Rate of Increase of Underground Temperature;—Fifth Report on Kent's Cavern, Devonshire;—Report on the Connexion between Chemical Constitution and Physiological Action;—On Emission, Absorption, and Reflection of Obscure Heat;—Report on Observations of Luminous Meteors;—Report on Uniformity of Weights and Measures; —Report on the Treatment and Utilization of Sewage;—Supplement to Second Report of the Steamship-Performance Committee;—Report on Recent Progress in Elliptic and Hyperelliptic Functions;—Report on Mineral Veins in Carboniferous Limestone and their Organic Contents;—Notes on the Foraminifera of Mineral Veins and the Adjacent Strata;—Report of the Rainfall Committee;—Interim Report on the Laws of the Flow and Action of Water containing Solid Matter in Suspension;—Interim Report on Agricultural Machinery;—Report on the Physiological Action of Methyl and Allied Series;—On the Influence of Form considered in Relation to the Strength of Railway-axles and other portions of Machinery subjected to Rapid Alterations of Strain;—On the Penetration of Armour-plates with Long Shells of Large Capacity fired obliquely;—Report on Standards of Electrical Resistance.

Together with the Transactions of the Sections, Prof. Stokes's Address, and Recommendations of the Associatian and its Committees.

PROCEEDINGS OF THE FORTIETH MEETING, at Liverpool, September 1870, *Published at* 18*s*.

CONTENTS:—Report on Steam-boiler Explosions;—Report of the Committee on the Hæmatite Iron-ores of Great Britain and Ireland;—Report on the Sedimentary Deposits of the River Onny;—Report on the Chemical Nature of Cast Iron;—Report on the practicability of establishing a 'Close Time' for the protection of Indigenous Animals;—Report on Standards of Electrical Resistance;—Sixth Report on Kent's Cavern;—Third Report on Underground Temperature;—Second Report of the Committee appointed to get cut and prepared Sections of Mountain-Limestone Corals;—Second Report on the Stability, Propulsion, and Sea-going Qualities of Ships;—Report on Earthquakes in Scotland;—Report on the Treatment and Utilization of Sewage;—Report on Observations of Luminous Meteors, 1869–70;—Report on Recent Progress in Elliptic and Hyperelliptic Functions;—Report on Tidal Observations;—On a new Steam-power Meter;—Report on the Action of the Methyl and Allied Series;—Report of the Rainfall Committee;—Report on the Heat generated in the Blood in the Process of Arterialization;—Report on the best means of providing for Uniformity of Weights and Measures.

Together with the Transactions of the Sections, Prof. Huxley's Address, and Recommendations of the Association and its Committees.

PROCEEDINGS OF THE FORTY-FIRST MEETING, at Edinburgh, August 1871, *Published at* 16*s*.

CONTENTS:—Seventh Report on Kent's Cavern;—Fourth Report on Underground Temperature;—Report on Observations of Luminous Meteors, 1870-71;—Fifth Report on the Structure and Classification of the Fossil Crustacea;—Report of the Committee appointed for the purpose of urging on Her Majesty's Government the expediency of arranging and tabulating the results of the approaching Census in the three several parts of the United Kingdom in such a manner as to admit of ready and effective comparison;—Report of the Committee appointed for the purpose of Superintending the Publication of Abstracts of Chemical Papers;—Report of the Committee for discussing Observations of Lunar Objects suspected of change;—Second Provisional Report on the Thermal Conductivity of Metals;—Report on the Rainfall of the British Isles;—Third Report on the British Fossil Corals;—Report on the Heat generated in the Blood during the Process of Arterialization;—Report of the Committee appointed to consider the subject of Physiological Experimentation;—Report on the Physiological Action of Organic Chemical Compounds;—Report of the Committee appointed to get cut and prepared Sections of Mountain-Limestone Corals;—Second Report on Steam-Boiler Explosions;—Report on the Treatment and Utilization of Sewage;—Report on promoting the Foundation of Zoological Stations in different parts of the World;—Preliminary Report on the Thermal Equivalents of the Oxides of Chlorine;—Report on the practicability of establishing a 'Close Time' for the protection of Indigenous Animals;—Report on Earthquakes in Scotland;—Report on the best means of providing for a Uniformity of Weights and Measures;—Report on Tidal Observations.

Together with the Transactions of the Sections, Sir William Thomson's Address, and Recommendations of the Association and its Committees.

PROCEEDINGS OF THE FORTY-SECOND MEETING, at Brighton, August 1872, *Published at* £1 4*s*.

CONTENTS:—Report on the Gaussian Constants for the Year 1829;—Second Supplementary Report on the Extinct Birds of the Mascarene Islands;—Report of the Committee for Superintending the Monthly Reports of the Progress of Chemistry;—Report of the Committee on the best means of providing for a Uniformity of Weights and Measures;—Eighth Report on Kent's Cavern;—Report on promoting the Foundation of Zoological Stations in different parts of the World;—Fourth Report on the Fauna of South Devon;—Preliminary Report of the Committee appointed to Construct and Print Catalogues of Spectral Rays arranged upon a Scale of Wave-numbers;—Third Report on Steam-Boiler Explosions;—Report on Observations of Luminous Meteors, 1871-72;—Experiments on the Surface-friction experienced by a Plane moving through Water;—Report of the Committee on the Antagonism between the Action of Active Substances;—Fifth Report on Underground Temperature;—Preliminary Report of the Committee on Siemens's Electrical-Resistance Pyrometer;—Fourth Report on the Treatment and Utilization of Sewage;—Interim Report of the Committee on Instruments for Measuring the Speed of Ships and Currents;—Report on the Rainfall of the British Isles;—Report of the Committee on a Geographical Exploration of the Country of Moab;—Sur l'élimination des Fonctions Arbitraires;—Report on the Discovery of Fossils in certain remote parts of the North-western Highlands;—Report of the Committee on Earthquakes in Scotland;—Fourth Report on Carboniferous-Limestone Corals;—Report of the Committee to consider the mode in which new Inventions and Claims for Reward in respect of adopted Inventions are examined and dealt with by the different Departments of Government;—Report of the Committee for discussing Observations of Lunar Objects suspected of change;—Report on the Mollusca of Europe;—Report of the Committee for investigating the Chemical Constitution and Optical Properties of Essential Oils;—Report on the practicability of establishing a 'Close Time' for the preservation of Indigenous Animals;—Sixth Report on the Structure and Classification of Fossil Crustacea;—Report of the Committee appointed to organize an Expedition for observing the Solar Eclipse of Dec. 12, 1871;—Preliminary Report of a Committee on Terato-embryological Inquiries;—Report on Recent Progress in

Elliptic and Hyperelliptic Functions;—Report on Tidal Observations;—On the Brighton Waterworks;—On Amsler's Planimeter.

Together with the Transactions of the Sections, Dr. Carpenter's Address, and Recommendations of the Association and its Committees.

PROCEEDINGS OF THE FORTY-THIRD MEETING, at Bradford, September 1873, *Published at £1 5s.*

CONTENTS:—Report of the Committee on Mathematical Tables;—Observations on the Application of Machinery to the Cutting of Coal in Mines;—Concluding Report on the Maltese Fossil Elephants;—Report of the Committee for ascertaining the Existence in different parts of the United Kingdom of any Erratic Blocks or Boulders;—Fourth Report on Earthquakes in Scotland;—Ninth Report on Kent's Cavern;—On the Flint and Chert Implements found in Kent's Cavern;—Report of the Committee for Investigating the Chemical Constitution and Optical Properties of Essential Oils;—Report of Inquiry into the Method of making Gold-assays;—Fifth Report on the Selection and Nomenclature of Dynamical and Electrical Units;—Report of the Committee on the Labyrinthodonts of the Coal-measures;—Report of the Committee appointed to construct and print Catalogues of Spectral Rays;—Report of the Committee appointed to explore the Settle Caves;—Sixth Report on Underground Temperature;—Report on the Rainfall of the British Isles;—Seventh Report on Researches in Fossil Crustacea;—Report on Recent Progress in Elliptic and Hyperelliptic Functions;—Report on the desirability of establishing a 'Close Time' for the preservation of Indigenous Animals;—Report on Luminous Meteors;—On the Visibility of the Dark Side of Venus;—Report of the Committee for the Foundation of Zoological Stations in different parts of the World;—Second Report of the Committee for collecting Fossils from North-western Scotland;—Fifth Report on the Treatment and Utilization of Sewage;—Report of the Committee on Monthly Reports of the Progress of Chemistry;—On the Bradford Waterworks;—Report on the possibility of Improving the Methods of Instruction in Elementary Geometry;—Interim Report of the Committee on Instruments for Measuring the Speed of Ships, &c.;—Report of the Committee for Determinating High Temperatures by means of the Refrangibility of Light evolved by Fluid or Solid Substances;—On a periodicity of Cyclones and Rainfall in connexion with Sun-spot Periodicity;—Fifth Report on the Structure of Carboniferous-Limestone Corals;—Report of the Committee on preparing and publishing brief forms of Instructions for Travellers, Ethnologists, &c.;—Preliminary Note from the Committee on the Influence of Forests on the Rainfall;—Report of the Sub-Wealden Exploration Committee;—Report of the Committee on Machinery for obtaining a Record of the Roughness of the Sea and Measurement of Waves near shore;—Report on Science Lectures and Organization;—Second Report on Science Lectures and Organization.

Together with the Transactions of the Sections, Prof. A. W. Williamson's Address, and Recommendations of the Association and its Committees.

PROCEEDINGS OF THE FORTY-FOURTH MEETING, at Belfast, August 1874, *Published at £1 5s.*

CONTENTS:—Tenth Report on Kent's Cavern;—Report for investigating the Chemical Constitution and Optical Properties of Essential Oils;—Second Report of the Sub-Wealden Exploration Committee;—On the Recent Progress and Present State of Systematic Botany;—Report of the Committee for investigating the Nature of Intestinal Secretion;—Report of the Committee on the Teaching of Physics in Schools;—Preliminary Report for investigating Isomeric Cresols and their Derivatives;—Third Report of the Committee for collecting Fossils from localities in North-western Scotland;—Report on the Rainfall of the British Isles;—On the Belfast Harbour;—Report of Inquiry into the Method of making Gold-assays;—Report of a Committee on Experiments to determine the Thermal Conductivities of certain Rocks;—Second Report on the Exploration of the Settle Caves;—On the Industrial uses of the Upper Bann River;—Report of the Committee on the Structure and Classification of the Labyrinthodont;—Second Report of the Committee for recording the position, height above the sea, lithological characters, size, and origin of the Erratic Blocks of England and Wales, &c.;—Sixth Report on the Treatment and Utilization of Sewage;—Report on the Anthropological Notes and Queries for the use of Travellers;—On Cyclone and Rainfall Periodicities;—Fifth Report on Earth-

quakes in Scotland;—Report of the Committee appointed to prepare and print Tables of Wave-numbers;—Report of the Committee for testing the new Pyrometer of Mr. Siemens;—Report to the Lords Commissioners of the Admiralty on Experiments for the Determination of the Frictional Resistance of Water on a Surface, &c.;—Second Report for the Selection and Nomenclature of Dynamical and Electrical Units;—On Instruments for measuring the Speed of Ships;—Report of the Committee on the possibility of establishing a 'Close Time' for the Protection of Indigenous Animals;—Report of the Committee to inquire into the economic effects of Combinations of Labourers and Capitalists;—Preliminary Report on Dredging on the Coasts of Durham and North Yorkshire;—Report on Luminous Meteors;—Report on the best means of providing for a Uniformity of Weights and Measures.

Together with the Transactions of the Sections, Prof. John Tyndall's Address, and Recommendations of the Association and its Committees.

PROCEEDINGS OF THE FORTY-FIFTH MEETING, at Bristol, August 1875, *Published at £1 5s.*

CONTENTS:—Eleventh Report on Kent's Cavern;—Seventh Report on Underground Temperature;—Report on the Zoological Station at Naples;—Report of a Committee appointed to inquire into the Methods employed in the Estimation of Potash and Phosphoric Acid in Commercial Products;—Report on the present state of our Knowledge of the Crustacea;—Second Report on the Thermal Conductivities of certain Rocks;—Preliminary Report of the Committee for extending the Observations on the Specific Volumes of Liquids;—Sixth Report on Earthquakes in Scotland;—Seventh Report on the Treatment and Utilization of Sewage;—Report of the Committee for furthering the Palestine Explorations;—Third Report of the Committee for recording the position, height above the sea, lithological characters, size, and origin of the Erratic Blocks of England and Wales, &c.;—Report of the Rainfall Committee;—Report of the Committee for investigating Isomeric Cresols and their Derivatives;—Report of the Committee for investigating the Circulation of the Underground Waters in the New Red Sandstone and Permian Formations of England;—On the Steering of Screw-Steamers;—Second Report of the Committee on Combinations of Capital and Labour;—Report on the Method of making Gold-assays;—Eighth Report on Underground Temperature;—Tides in the River Mersey;—Sixth Report of the Committee on the Structure of Carboniferous Corals;—Report of the Committee appointed to explore the Settle Caves;—On the River Avon (Bristol), its Drainage-Area, &c.;—Report of the Committee on the possibility of establishing a 'Close Time' for the Protection of Indigenous Animals;—Report of the Committee appointed to superintend the Publication of the Monthly Reports of the Progress of Chemistry;—Report on Dredging off the Coasts of Durham and North Yorkshire in 1874;—Report on Luminous Meteors;—On the Analytical Forms called Trees;—Report of the Committee on Mathematical Tables;—Report of the Committee on Mathematical Notation and Printing;—Second Report of the Committee for investigating Intestinal Secretion;—Third Report of the Sub-Wealden Exploration Committee.

Together with the Transactions of the Sections, Sir John Hawkshaw's Address, and Recommendations of the Association and its Committees.

PROCEEDINGS OF THE FORTY-SIXTH MEETING, at Glasgow, September 1876, *Published at £1 5s.*

CONTENTS:—Twelfth Report on Kent's Cavern;—Report on Improving the Methods of Instruction in Elementary Geometry;—Results of a Comparison of the British-Association Units of Electrical Resistance;—Third Report on the Thermal Conductivities of certain Rocks;—Report of the Committee on the practicability of adopting a Common Measure of Value in the Assessment of Direct Taxation;—Report of the Committee for testing experimentally Ohm's Law;—Report of the Committee on the possibility of establishing a 'Close Time' for the Protection of Indigenous Animals;—Report of the Committee on the Effect of Propellers on the Steering of Vessels;—On the Investigation of the Steering Qualities of Ships;—Seventh Report on Earthquakes in Scotland;—Report on the present state of our Knowledge of the Crustacea;—Second Report of the Committee for investigating the Circulation of the Underground Waters in the New Red Sandstone and Permian Formations of England;—Fourth Report of the Committee on the Erratic Blocks of England and Wales, &c.;—Fourth Report of the Committee on the Exploration of

the Settle Caves (Victoria Cave);—Report on Observations of Luminous Meteors, 1875–76;—Report on the Rainfall of the British Isles, 1875–76;—Ninth Report on Underground Temperature;—Nitrous Oxide in the Gaseous and Liquid States;—Eighth Report on the Treatment and Utilization of Sewage;—Improved Investigations on the Flow of Water through Orifices, with Objections to the modes of treatment commonly adopted;—Report of the Anthropometric Committee;—On Cyclone and Rainfall Periodicities in connexion with the Sun-spot Periodicity;—Report of the Committee for determining the Mechanical Equivalent of Heat;—Report of the Committee on Tidal Observations;—Third Report of the Committee on the Conditions of Intestinal Secretion and Movement;—Report of the Committee for collecting and suggesting subjects for Chemical Research.

Together with the Transactions of the Sections, Dr. T. Andrews's Address, and Recommendations of the Association and its Committees.

PROCEEDINGS OF THE FORTY-SEVENTH MEETING, at Plymouth, August 1877, *Published at £1 4s.*

CONTENTS:—Thirteenth Report on Kent's Cavern;—Second and Third Reports on the Methods employed in the estimation of Potash and Phosphoric Acid in Commercial Products;—Report on the present state of our Knowledge of the Crustacea (Part III.);—Third Report on the Circulation of the Underground Waters in the New Red Sandstone and Permian Formations of England;—Fifth Report on the Erratic Blocks of England, Wales, and Ireland;—Fourth Report on the Thermal Conductivities of certain Rocks;—Report on Observations of Luminous Meteors, 1876–77;—Tenth Report on Underground Temperature;—Report on the Effect of Propellers on the Steering of Vessels;—Report on the possibility of establishing a 'Close Time' for the Protection of Indigenous Animals;—Report on some Double Compounds of Nickel and Cobalt;—Fifth Report on the Exploration of the Settle Caves (Victoria Cave);—Report on the Datum Level of the Ordnance Survey of Great Britain;—Report on the Zoological Station at Naples;—Report of the Anthropometric Committee;—Report on the Conditions under which Liquid Carbonic Acid exists in Rocks and Minerals.

Together with the Transactions of the Sections, Prof. Allen Thomson's Address, and Recommendations of the Association and its Committees.

PROCEEDINGS OF THE FORTY-EIGHTH MEETING, at Dublin, August 1878, *Published at £1 4s.*

CONTENTS:—Catalogue of the Oscillation-Frequencies of Solar Rays;—Report on Mr. Babbage's Analytical Machine;—Third Report of the Committee for determining the Mechanical Equivalent of Heat;—Report of the Committee for arranging for the taking of certain Observations in India, and Observations on Atmospheric Electricity at Madeira;—Report on the commencement of Secular Experiments upon the Elasticity of Wires;—Report on the Chemistry of some of the lesser-known Alkaloids, especially Veratria and Bebeerine;—Report on the best means for the Development of Light from Coal-Gas;—Fourteenth Report on Kent's Cavern;—Report on the Fossils in the North-west Highlands of Scotland;—Fifth Report on the Thermal Conductivities of certain Rocks;—Report on the possibility of establishing a 'Close Time' for the Protection of Indigenous Animals;—Report on the occupation of a Table at the Zoological Station at Naples;—Report of the Anthropometric Committee;—Report on Patent Legislation;—Report on the Use of Steel for Structural Purposes;—Report on the Geographical Distribution of the Chiroptera;—Recent Improvements in the Port of Dublin;—Report on Mathematical Tables;—Eleventh Report on Underground Temperature;—Report on the Exploration of the Fermanagh Caves;—Sixth Report on the Erratic Blocks of England, Wales, and Ireland;—Report on the present state of our Knowledge of the Crustacea (Part IV.);—Report on two Caves in the neighbourhood of Tenby;—Report on the Stationary Tides in the English Channel and in the North Sea, &c.;—Second Report on the Datum-level of the Ordnance Survey of Great Britain;—Report on Instruments for measuring the Speed of Ships;—Report of Investigations into a Common Measure of Value in Direct Taxation;—Report on Sunspots and Rainfall;—Report on Observations of Luminous Meteors;—Sixth Report on the Exploration of the Settle Caves (Victoria Cave);—Report on the Kentish Boring Exploration;—Fourth Report on the Circulation of Underground Waters in the Jurassic, New Red

Sandstone, and Permian Formations, with an Appendix on the Filtration of Water through Triassic Sandstone;—Report on the Effect of Propellers on the Steering of Vessels.

Together with the Transactions of the Sections, Mr. Spottiswoode's Address, and Recommendations of the Association and its Committees.

PROCEEDINGS OF THE FORTY-NINTH MEETING, at Sheffield, August 1879, *Published at £1 4s.*

CONTENTS:—Report on the commencement of Secular Experiments upon the Elasticity of Wires;—Fourth Report of the Committee for determining the Mechanical Equivalent of Heat;—Report of the Committee for endeavouring to procure reports on the Progress of the Chief Branches of Mathematics and Physics;—Twelfth Report on Underground Temperature;—Report on Mathematical Tables;—Sixth Report on the Thermal Conductivities of certain Rocks;—Report on Observations of Atmospheric Electricity at Madeira;—Report on the Calculation of Tables of the Fundamental Invariants of Algebraic Forms;—Report on the Calculation of Sun-Heat Coefficients;—Second Report on the Stationary Tides in the English Channel and in the North Sea, &c.;—Report on Observations of Luminous Meteors;—Report on the question of Improvements in Astronomical Clocks;—Report of the Committee for improving an Instrument for detecting the presence of Fire-damp in Mines;—Report on the Chemistry of some of the lesser-known Alkaloids, especially Veratria and Beeberine;—Seventh Report on the Erratic Blocks of England, Wales, and Ireland;—Fifteenth Report on Kent's Cavern;—Report on certain Caves in Borneo;—Fifth Report on the Circulation of Underground Waters in the Jurassic, Red Sandstone, and Permian Formations of England;—Report on the Tertiary (Miocene) Flora, &c., of the Basalt of the North of Ireland;—Report on the possibility of Establishing a 'Close Time' for the Protection of Indigenous Animals;—Report on the Marine Zoology of Devon and Cornwall;—Report on the Occupation of a Table at the Zoological Station at Naples;—Report on Excavations at Portstewart and elsewhere in the North of Ireland;—Report of the Anthropometric Committee;—Report on the Investigation of the Natural History of Socotra;—Report on Instruments for measuring the Speed of Ships;—Third Report on the Datum-level of the Ordnance Survey of Great Britain;—Second Report on Patent Legislation;—On Self-acting Intermittent Siphons and the conditions which determine the commencement of their Action;—On some further Evidence as to the Range of the Palæozoic Rocks beneath the South-east of England;—Hydrography, Past and Present.

Together with the Transactions of the Sections, Prof. Allman's Address, and Recommendations of the Association and its Committees.

PROCEEDINGS OF THE FIFTIETH MEETING, at Swansea, August and September 1880, *Published at £1 4s.*

CONTENTS:—Report on the Measurement of the Lunar Disturbance of Gravity;—Thirteenth Report on Underground Temperature;—Report of the Committee for devising and constructing an improved form of High Insulation Key for Electrometer Work;—Report on Mathematical Tables;—Report on the Calculation of Tables of the Fundamental Invariants of Algebraic Forms;—Report on Observations of Luminous Meteors;—Reports on the question of Improvements in Astronomical Clocks;—Report on the commencement of Secular Experiments on the Elasticity of Wires;—Sixteenth and concluding Report on Kent's Cavern;—Report on the mode of reproduction of certain species of Ichthyosaurus from the Lias of England and Würtemburg;—Report on the Carboniferous Polyzoa;—Report on the 'Geological Record';—Sixth Report on the Circulation of the Underground Waters in the Permian, New Red Sandstone, and Jurassic Formations of England, and the Quantity and Character of the Water supplied to towns and districts from these formations;—Second Report on the Tertiary (Miocene) Flora, &c., of the Basalt of the North of Ireland;—Eighth Report on the Erratic Blocks of England, Wales, and Ireland;—Report on an Investigation for the purpose of fixing a Standard of White Light;—Report of the Anthropometric Committee;—Report on the Influence of Bodily Exercise on the Elimination of Nitrogen;—Second Report on the Marine Zoology of South Devon;—Report on the Occupation of a Table at the Zoological Station at Naples;—Report on accessions to our knowledge of the Chiroptera during the past two years

(1878–80);—Preliminary Report on the accurate measurement of the specific inductive capacity of a good Sprengel Vacuum, and the specific resistance of gases at different pressures;—Comparison of Curves of the Declination Magnetographs at Kew, Stonyhurst, Coimbra, Lisbon, Vienna, and St. Petersburg;—First Report on the Caves of the South of Ireland;—Report on the Investigation of the Natural History of Socotra;—Report on the German and other systems of teaching the Deaf to speak;—Report of the Committee for considering whether it is important that H.M. Inspectors of Elementary Schools should be appointed with reference to their ability for examining in the scientific specific subjects of the Code in addition to other matters;—On the Anthracite Coal and Coalfield of South Wales;—Report on the present state of our knowledge of Crustacea (Part V.);—Report on the best means for the Development of Light from Coal-gas of different qualities (Part II.);—Report on Palæontological and Zoological Researches in Mexico;—Report on the possibility of establishing a 'Close Time' for Indigenous Animals;—Report on the present state of our knowledge of Spectrum Analysis;—Report on Patent Legislation;—Preliminary Report on the present Appropriation of Wages, &c.;—Report on the present state of knowledge of the application of Quadratures and Interpolation to Actual Data;—The French Deep-sea Exploration in the Bay of Biscay;—Third Report on the Stationary Tides in the English Channel and in the North Sea, &c.;—List of Works on the Geology, Mineralogy, and Palæontology of Wales (to the end of 1873);—On the recent Revival in Trade.

Together with the Transactions of the Sections, Dr. A. C. Ramsay's Address, and Recommendations of the Association and its Committees.

PROCEEDINGS OF THE FIFTY-FIRST MEETING, at York, August and September 1881, *Published at £1 4s.*

CONTENTS:—Report on the Calculation of Tables of the Fundamental Invariants of Algebraic Forms;—Report on Recent Progress in Hydrodynamics (Part I.);—Report on Meteoric Dust;—Second Report on the Calculation of Sun-heat Coefficients;—Fourteenth Report on Underground Temperature;—Report on the Measurement of the Lunar Disturbance of Gravity;—Second Report on an Investigation for the purpose of fixing a Standard of White Light;—Final Report on the Thermal Conductivities of certain Rocks;—Report on the manner in which Rudimentary Science should be taught, and how Examinations should be held therein, in Elementary Schools;—Third Report on the Tertiary Flora of the North of Ireland;—Report on the Method of Determining the Specific Refraction of Solids from their Solutions;—Fourth Report on the Stationary Tides in the English Channel and in the North Sea, &c;—Second Report on Fossil Polyzoa;—Report on the Maintenance of the Scottish Zoological Station;—Report on the Occupation of a Table at the Zoological Station at Naples;—Report on the Migration of Birds;—Report on the Natural History of Socotra;—Report on the Natural History of Timor-laut;—Report on the Marine Fauna of the Southern Coast of Devon and Cornwall;—Report on the Earthquake Phenomena of Japan;—Ninth Report on the Erratic Blocks of England, Wales, and Ireland;—Second Report on the Caves of the South of Ireland;—Report on Patent Legislation;—Report of the Anthropometric Committee;—Report on the Appropriation of Wages, &c.;—Report on Observations of Luminous Meteors;—Report on Mathematical Tables;—Seventh Report on the Circulation of Underground Waters in the Jurassic, New Red Sandstone, and Permian Formations of England, and the Quality and Quantity of the Water supplied to Towns and Districts from these Formations;—Report on the present state of our Knowledge of Spectrum Analysis;—Interim Report of the Committee for constructing and issuing practical Standards for use in Electrical Measurements;—On some new Theorems on Curves of Double Curvature;—Observations of Atmospheric Electricity at the Kew Observatory during 1880;—On the Arrestation of Infusorial Life by Solar Light;—On the Effects of Oceanic Currents upon Climates;—On Magnetic Disturbances and Earth Currents;—On some Applications of Electric Energy to Horticultural and Agricultural purposes;—On the Pressure of Wind upon a Fixed Plane Surface;—On the Island of Socotra;—On some of the Developments of Mechanical Engineering during the last Half-Century.

Together with the Transactions of the Sections, Sir John Lubbock's Address, and Recommendations of the Association and its Committees.

Spottiswoode & Co., Printers, New-street Square, London.

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FOR

THE ADVANCEMENT OF SCIENCE.

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1883.

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* § indicates Annual Subscribers entitled to the Annual Report.
* ‡ indicates Subscribers not entitled to the Annual Report.

Names without any mark before them are Life Members not entitled to the Annual Report.

Names of Members of the GENERAL COMMITTEE are printed in SMALL CAPITALS.

Names of Members whose addresses are incomplete or not known are in *italics*.

Notice of changes of residence should be sent to the Secretary, 22 Albemarle Street, London, W.

Year of Election.

Abbatt, Richard, F.R.A.S. Marlborough House, Burgess Hill, Sussex.

1881. *Abbott, R. T. G. Auburn Hill, Malton, Yorkshire.

1863. *ABEL, FREDERICK AUGUSTUS, C.B., F.R.S., F.C.S., Director of the Chemical Establishment of the War Department. Royal Arsenal, Woolwich.

1856. ‡Abercrombie, John, M.D. 13 Suffolk-square, Cheltenham.

1863. *ABERNETHY, JAMES, M.Inst.C.E., F.R.S.E. 4 Delahay-street, Westminster, S.W.

1873. ‡Abernethy, James. Ferry-hill, Aberdeen.

1860. ‡Abernethy, Robert. Ferry-hill, Aberdeen.

1873. *ABNEY, Captain W. DE W., R.E., F.R.S., F.R.A.S., F.C.S. 3 St. Alban's-road, Kensington, London, W.

1877. §Ace, Rev. Daniel, D.D., F.R.A.S. Laughton, near Gainsborough, Lincolnshire.

1873. ‡Ackroyd, Samuel. Greaves-street, Little Horton, Bradford, Yorkshire.

1882. *Acland, Alfred Dyke. Oxford.

1869. ‡Acland, Charles T. D. Sprydoncote, Exeter.

1877. *Acland, Francis E. Dyke, R.A. Oxford.

1873. *Acland, Rev. H. D., M.A. Nymet St. George, South Molton, Devon.

Year of Election.

1873. *Acland, Henry W. D., M.A., M.D., LL.D., F.R.S., F.R.G.S., Radcliffe Librarian and Regius Professor of Medicine in the University of Oxford. Broad-street, Oxford.
1877. *Acland, Theodore Dyke, M.A. 13 Vincent-square, Westminster, S.W.
1860. ‡Acland, Sir Thomas Dyke, Bart., M.A., D.C.L., M.P. Sprydoncote, Exeter; and Athenæum Club, London, S.W.
Adair, John. 13 Merrion-square North, Dublin.
1876. ‡Adams, James. 9 Royal-crescent West, Glasgow.
*Adams, John Couch, M.A., LL.D., F.R.S., F.R.A.S., Director of the Observatory and Lowndean Professor of Astronomy and Geometry in the University of Cambridge. The Observatory, Cambridge.
1871. §Adams, John R. 3 Queen's-gate-terrace, London, S.W.
1879. *Adams, Rev. Thomas, M.A. Clifton Green House, York.
1877. ‡Adams, William. 3 Sussex-terrace, Plymouth.
1869. *Adams, William Grylls, M.A., F.R.S., F.G.S., F.C.P.S., Professor of Natural Philosophy and Astronomy in King's College, London. 43 Notting Hill-square, London, W.
1873. ‡Adams-Acton, John. Margutta House, 103 Marylebone-road, London, N.W.
1879. ‡Adamson, Robert, M.A., Professor of Logic and Political Economy in Owens College, Manchester. 60 Parsonage-road, Withington, Manchester.
1865. *Adkins, Henry. Northfield, near Birmingham.
1864. *Ainsworth, David. The Flosh, Cleator, Carnforth.
1871. *Ainsworth, John Stirling. Harecroft, Cumberland.
Ainsworth, Peter. Smithills Hall, Bolton.
1842. *Ainsworth, Thomas. The Flosh, Cleator, Carnforth.
1871. ‡Ainsworth, William M. The Flosh, Cleator, Carnforth.
Airy, Sir George Biddell, K.C.B., M.A., LL.D., D.C.L., F.R.S., F.R.A.S. The White House, Croom's Hill, Greenwich, S.E.
1871. §Aitken, John, F.R.S.E. Darroch, Falkirk, N.B.
Akroyd, Edward. Bankfield, Halifax.
1862. ‡Alcock, Sir Rutherford, K.C.B., D.C.L., F.R.G.S. The Athenæum Club, Pall Mall, London, S.W.
1861. ‡Alcock, Thomas, M.D. Side Brook, Salemoor, Manchester.
1872. *Alcock, Thomas, M.D. Oakfield, Sale, Manchester.
*Aldam, William. Frickley Hall, near Doncaster.
1859. ‡Alexander, General Sir James Edward, K.C.B., K.C.L.S., F.R.S.E., F.R.A.S., F.R.G.S. Westerton, Bridge of Allan, N.B.
1873. ‡Alexander, Reginald, M.D. 13 Hallfield-road, Bradford, Yorkshire.
1858. ‡Alexander, William, M.D. Halifax.
1850. ‡Alexander, Rev. William Lindsay, D.D., F.R.S.E. Pinkieburn, Musselburgh, by Edinburgh.
1867. ‡Alison, George L. C. Dundee.
1859. ‡Allan, Alexander. Scottish Central Railway, Perth.
1871. ‡Allan, G., C.E. 17 Leadenhall-street, London, E.C.
1871. ‡Allen, Alfred H., F.C.S. 1 Surrey-street, Sheffield.
1879. *Allen, Rev. A. J. C. Peterhouse, Cambridge.
1878. ‡Allen, John Romilly. 5 Albert-terrace, Regent's Park, London, N.W.
1861. ‡Allen, Richard. Didsbury, near Manchester.
1852. *Allen, William J. C., Secretary to the Royal Belfast Academical Institution. Ulster Bank, Belfast.
1863. ‡Allhusen, C. Elswick Hall, Newcastle-on-Tyne.

Year of Election.

*ALLMAN, GEORGE J., M.D., LL.D., F.R.S. L. & E., M.R.I.A., F.L.S., Emeritus Professor of Natural History in the University of Edinburgh. Ardmoor, Parkstone, Dorset.
1873. ‡Ambler, John. North Park-road, Bradford, Yorkshire.
1876. ‡Anderson, Alexander. 1 St. James's-place, Hillhead, Glasgow.
1878. ‡Anderson, Beresford. Saint Ville, Killiney.
1850. ‡Anderson, Charles William. Cleadon, South Shields.
1850. ‡Anderson, John. 31 St. Bernard's-crescent, Edinburgh.
1874. ‡Anderson, John, J.P., F.G.S. Holywood, Belfast.
1876. ‡Anderson, Matthew. 137 St. Vincent-street, Glasgow.
1859. ‡ANDERSON, PATRICK. 15 King-street, Dundee.
1880. ‡*Anderson, Richard. New Malden, Surrey.*
1880. *ANDERSON, TEMPEST, M.D., B.Sc. 17 Stonegate, York.
1880. §Andrew, Mrs. 126 Jamaica-street, Stepney, London, E.
1880. *Andrews, Thornton, M.I.C.E. Cefn Eithen, Swansea.
*ANDREWS, THOMAS, M.D., LL.D., F.R.S., Hon. F.R.S.E., M.R.I.A., F.C.S. Fortwilliam Park, Belfast.
1877. §ANGELL, JOHN, F.C.S. 81 Ducie-grove, Oxford-street, Manchester.
1859. ‡Angus, John. Town House, Aberdeen.
1878. ‡Anson, Frederick H. 9 Delahay-street, Westminster, S.W.
Anthony, John, M.D. 6 Greenfield-crescent, Edgbaston, Birmingham.
APJOHN, JAMES, M.D., F.R.S., F.C.S., M.R.I.A., Professor of Mineralogy at Dublin University. South Hill, Blackrock, Co. Dublin.
1868. ‡Appleby, C. J. Emerson-street, Bankside, Southwark, London, S.E.
1870. ‡Archer, Francis, jun. 3 Brunswick-street, Liverpool.
1855. *ARCHER, Professor THOMAS C., F.R.S.E., Director of the Museum of Science and Art, Edinburgh. St. Margaret's, Greenhill-place, Edinburgh.
1874. ‡Archer, William, F.R.S., M.R.I.A. St. Brendan's, Grosvenor-road East, Rathmines, Dublin.
1851. ‡ARGYLL, His Grace the Duke of, K.T., D.C.L., F.R.S. L.&E., F.G.S. Argyll Lodge, Kensington, London, W.; and Inveraray, Argyleshire.
1861. ‡Armitage, William. 95 Portland-street, Manchester.
1867. *Armitstead, George. Errol Park, Errol, N.B.
1879. *Armstrong, Sir Alexander, K.C.B., LL.D., F.R.S., F.R.G.S. The Albany, London, W.
1873. §Armstrong, Henry E., Ph.D., F.R.S., F.C.S. London Institution, Finsbury-circus, London, E.C.
1878. ‡Armstrong, James. 28A Renfield-street, Glasgow.
Armstrong, Thomas. Higher Broughton, Manchester.
1857. *ARMSTRONG, Sir WILLIAM GEORGE, C.B., LL.D., D.C.L., F.R.S. 8 Great George-street, London, S.W.; and Jesmond Dene, Newcastle-upon-Tyne.
1870. ‡Arnott, Thomas Reid. Bramshill, Harlesden Green, London, N.W.
1853. *Arthur, Rev. William, M.A. Clapham Common, London, S.W.
1870. *Ash, Dr. T. Linnington. Holsworthy, North Devon.
1874. ‡Ashe, Isaac, M.B. Dundrum, Co. Dublin.
1873. §Ashton, John. Gorse Bank House, Windsor-road, Oldham.
1842. *Ashton, Thomas, M.D. 8 Royal Wells-terrace, Cheltenham.
Ashton, Thomas. Ford Bank, Didsbury, Manchester.
1866. ‡Ashwell, Henry. Mount-street, New Basford, Nottingham.
*Ashworth, Edmund. Egerton Hall, Bolton-le-Moors.
Ashworth, Henry. Turton, near Bolton.
1861. ‡Aspland, Alfred. Dukinfield, Ashton-under-Lyne.

Year of Election.

1875. *Aspland, W. Gaskell. Care of Manager, Union Bank, Chancery-lane, London, W.C.
1861. §Asquith, J. R. Infirmary-street, Leeds.
1861. ‡Aston, Theodore. 11 New-square, Lincoln's Inn, London, W.C.
1872. §Atchison, Arthur T., M.A. 60 Warwick-road, Earl's Court, London, S.W.
1858. ‡Atherton, Charles. Sandover, Isle of Wight.
1865. ‡*Atkin, Alfred. Griffin's Hill, Birmingham.*
1861. ‡Atkin, Eli. Newton Heath, Manchester.
1865. *Atkinson, Edmund, Ph.D., F.C.S. Portesbery Hill, Camberley, Surrey.
1863. *Atkinson, G. Clayton. 21 Windsor-terrace, Newcastle-on-Tyne.
1861. ‡Atkinson, Rev. J. A. Longsight Rectory, near Manchester.
1858. *Atkinson, John Hastings. 12 East Parade, Leeds.
1842. *Atkinson, Joseph Beavington. Stratford House, 113 Abingdon-road, Kensington, London, W.
1881. ‡Atkinson, J. T. The Quay, Selby, Yorkshire.
1881. ‡Atkinson, Robert William. Town Hall-buildings, Newcastle-on-Tyne.
1858. Atkinson, William. Claremont, Southport.
1863. *Attfield, Professor J., Ph.D., F.R.S., F.C.S. 17 Bloomsbury-square, London, W.C.
1860. *Austin-Gourlay, Rev. William E. C., M.A. The Rectory, Stanton St. John, near Oxford.
1865. *Avery, Thomas. Church-road, Edgbaston, Birmingham.
1881. §Axon, W. E. A. Fern Bank, Higher Broughton, Manchester.
1878. *Aylmer, Sir Gerald George, Bart. Donadea Castle, Kilcock, Co. Kildare.
1877. *Ayrton, W. E., F.R.S., Professor of Applied Physics in the City and Guilds of London Technical College. 68 Sloane-street, London, S.W.
1853. *Ayrton, W. S., F.S.A. Cliffden, Saltburn-by-the-Sea.

*Babington, Charles Cardale, M.A., F.R.S., F.L.S., F.G.S., Professor of Botany in the University of Cambridge. 5 Brookside, Cambridge.
Backhouse, Edmund. Darlington.
Backhouse, Thomas James. Sunderland.
1863. ‡Backhouse, T. W. West Hendon House, Sunderland.
1877. ‡Badock, W. F. Badminton House, Clifton Park, Bristol.
1870. §Bailey, Dr. F. J. 51 Grove-street, Liverpool.
1878. ‡Bailey, John. 3 Blackhall-place, Dublin.
1865. ‡Bailey, Samuel, F.G.S. The Peck, Walsall.
1855. ‡Bailey, William. Horseley Fields Chemical Works, Wolverhampton.
1866. ‡Baillon, Andrew. St. Mary's Gate, Nottingham.
1866. ‡Baillon, L. St. Mary's Gate, Nottingham.
1878. ‡Baily, Walter. 176 Haverstock-hill, London, N.W.
1857. ‡Baily, William Hellier, F.L.S., F.G.S., Acting Palæontologist to the Geological Survey of Ireland. 14 Hume-street; and Apsley Lodge, 92 Rathgar-road, Dublin.
1873. ‡Bain, Sir James. 3 Park-terrace, Glasgow.
*Bainbridge, Robert Walton. Middleton House, Middleton-in-Teesdale, by Darlington.
*Baines, Sir Edward, J.P. Belgrave Mansions, Grosvenor-gardens, London, S.W.; and St. Ann's Hill, Burley, Leeds.
1858. ‡Baines, Frederick. Burley, near Leeds.

Year of Election.

1858. ‡Baines, T. Blackburn. 'Mercury' Office, Leeds.
1882. §Baker, Benjamin, M.I.C.E. 2 Queen Square-place, Westminster, S.W.
1866. ‡Baker, Francis B. Sherwood-street, Nottingham.
1865. ‡Baker, James P. Wolverhampton.
1861. *Baker, John. St. John's-road, Buxton.
1881. ‡Baker, Robert, M.D. The Retreat, York.
1865. ‡Baker, Robert L. Barham House, Leamington.
1863. ‡Baker, William. 6 Taptonville, Sheffield.
1875. *Baker, W. Mills. Moorland House, Stoke Bishop, near Bristol.
1875. ‡BAKER, W. PROCTOR. Brislington, Bristol.
1881. ‡Baldwin, Rev. G. W. de Courcy, M.A. Lord Mayor's Walk, York.
1871. ‡Balfour, G. W. Whittinghame, Prestonkirk, Scotland.
1875. ‡BALFOUR, ISAAC BAYLEY, D.Sc., M.B., F.R.S.E., Professor of Botany in the University of Glasgow. Glasgow.
*BALFOUR, JOHN HUTTON, M.A., M.D., LL.D., F.R.S. L. & E., F.L.S., Emeritus Professor of Botany. Inverleith House, Edinburgh.
1878. *Ball, Charles Bent, M.D. 16 Lower Fitzwilliam-street, Dublin.
*BALL, JOHN, M.A., F.R.S., F.L.S., M.R.I.A. 10 Southwell-gardens, South Kensington, London, S.W.
1866. *BALL, ROBERT STAWELL, M.A., LL.D., F.R.S., F.R.A.S., Andrews Professor of Astronomy in the University of Dublin, and Astronomer Royal for Ireland. The Observatory, Dunsink, Co. Dublin.
1878. ‡BALL, VALENTINE, M.A., F.R.S., F.G.S., Professor of Geology and Mineralogy in the University of Dublin.
1869. ‡Bamber, Henry K., F.C.S. 5 Westminster-chambers, Victoria-street, Westminster, S.W.
1882. §Bance, Edward. Limewood, The Avenue, Southampton.
1852. ‡Bangor, Viscount. Castleward, Co. Down, Ireland.
1879. ‡Banham, H. French. Mount View, Glossop-road, Sheffield.
1870. ‡BANISTER, Rev. WILLIAM, B.A. St. James's Mount, Liverpool.
1866. ‡Barber, John. Long-row, Nottingham.
1861. *Barbour, George. Bankhead, Broxton, Chester.
1859. ‡Barbour, George F. 11 George-square, Edinburgh.
*Barbour, Robert. Bolesworth Castle, Tattenhall, Chester.
1855. ‡Barclay, Andrew. Kilmarnock, Scotland.
Barclay, Charles, F.S.A. Bury Hill, Dorking.
1871. ‡Barclay, George. 17 Coates-crescent, Edinburgh.
1852. *Barclay, J. Gurney. 54 Lombard-street, London, E.C.
1860. *Barclay, Robert. High Leigh, Hoddesden, Herts.
1876. *Barclay, Robert. 21 Park-terrace, Glasgow.
1868. *Barclay, W. L. 54 Lombard-street, London, E.C.
1881. §Barfoot, William, J.P. Whelford-place, Leicester.
1882. §Barford, J. G. Above Bar, Southampton.
1863. *Barford, James Gale, F.C.S. Wellington College, Wokingham, Berkshire.
1860. *Barker, Rev. Arthur Alcock, B.D. East Bridgford Rectory, Nottingham.
1879. ‡Barker, Elliott. 2 High-street, Sheffield.
1882. *Barker, Miss J. M. Hexham House, Hexham.
1879. *Barker, Rev. Philip C., M.A., LL.B. Rotherham, Yorkshire.
1865. ‡Barker, Stephen. 30 Frederick-street, Edgbaston, Birmingham.
1870. ‡BARKLY, Sir HENRY, G.C.M.G., K.C.B., F.R.S., F.R.G.S. 1 Bina-gardens, South Kensington, London, S.W.
1873. ‡Barlow, Crawford, B.A. 2 Old Palace-yard, Westminster, S.W.
1878. ‡Barlow, John, M.D., Professor of Physiology in Anderson's College, Glasgow.

Year of Election.

Barlow, Lieut.-Col. Maurice (14th Regt. of Foot). 5 Great George-street, Dublin.
1857. ‡BARLOW, PETER WILLIAM, F.R.S., F.G.S. 26 Great George-street, Westminster, S.W.
1873. §BARLOW, W. H., C.E., F.R.S. 2 Old Palace-yard, Westminster, S.W.
1861. *Barnard, Major R. Cary, F.L.S. Bartlow, Leckhampton, Cheltenham.
1868. §Barnes, Richard H. (Care of Messrs. Collyer, 4 Bedford-row, London, W.C.)
Barnes, Thomas Addison. Brampton Collieries, near Chesterfield.
*Barnett, Richard, M.R.C.S. 18 Binswood-avenue, Leamington.
1881. ‡Barr, Archibald, B.Sc., C.E. Castlehead, Paisley.
1859. ‡Barr, Lieut.-General. Apsleytoun, East Grinstead, Sussex.
1860. ‡Barrett, T. B. High-street, Welshpool, Montgomery.
1872. *BARRETT, W. F., F.R.S.E., M.R.I.A., F.C.S., Professor of Physics in the Royal College of Science, Dublin.
1874. ‡Barrington, R. M. Fassaroe, Bray, Co. Wicklow.
1874. §Barrington-Ward, Mark J., M.A., F.L.S., F.R.G.S., H.M. Inspector of Schools. Salwarpe End, Droitwich.
1881. §Barron, G. B., M.D. Summerseat, Southport.
1866. ‡Barron, William. Elvaston Nurseries, Borrowash, Derby.
1858. ‡BARRY, Rev. Canon, D.D., D.C.L., Principal of King's College, London, W.C.
1862. *Barry, Charles. 15 Pembridge-square, Bayswater, London, W.
1875. ‡Barry, John Wolfe. 23 Delahay-street, Westminster, S.W.
1881. ‡Barry, J. W. Duncombe-place, York.
Barstow, Thomas. Garrow Hill, near York.
1858. *Bartholomew, Charles. Castle Hill House, Ealing, Middlesex, W.
1855. ‡Bartholomew, Hugh. New Gasworks, Glasgow.
1858. *Bartholomew, William Hamond. Ridgeway House, Cumberland-road, Headingley, Leeds.
1873. ‡Bartley, George C. T. St. Margaret's House, Victoria-street, London, S.W.
1868. *Barton, Edward (27th Inniskillens). Clonelly, Ireland.
1857. ‡Barton, Folloit W. Clonelly, Co. Fermanagh.
1852. ‡Barton, James. Farndreg, Dundalk.
1864. ‡Bartrum, John S. 41 Gay-street, Bath.
*Bashforth, Rev. Francis, B.D. Minting Vicarage, near Horncastle.
1876. ‡Bassano, Alexander. 12 Montagu-place, London, W.
1876. ‡Bassano, Clement. Jesus College, Cambridge.
1866. *BASSETT, HENRY. 26 Belitha-villas, Barnsbury, London, N.
1866. ‡Bassett, Richard. Pelham-street, Nottingham.
1869. ‡Bastard, S. S. Summerland-place, Exeter.
1871. ‡BASTIAN, H. CHARLTON, M.D., M.A., F.R.S., F.L.S., Professor of Pathological Anatomy at University College, London. 20 Queen Anne-street, London, W.
1848. ‡BATE, C. SPENCE, F.R.S., F.L.S. 8 Mulgrave-place, Plymouth.
1873. *Bateman, Daniel. Carpenter-street, above Broad-street, Philadelphia, United States.
1868. ‡Bateman, Frederick, M.D. Upper St. Giles's-street, Norwich.
BATEMAN, JAMES, M.A., F.R.S., F.R.G.S., F.L.S. 9 Hyde Park-gate South, London, W.
1842. *BATEMAN, JOHN FREDERIC, C.E., F.R.S., F.G.S., F.R.G.S. 16 Great George-street, London, S.W.
1864. ‡BATES, HENRY WALTER, F.R.S., F.L.S., Assist.-Sec. R.G.S. 1 Savile-row, London, W.
1852. ‡Bateson, Sir Robert, Bart. Belvoir Park, Belfast.

Year of Election.

1851. ‡Bath and Wells, The Right Rev. Lord Arthur Hervey, Lord Bishop of. The Palace, Wells, Somerset.
1881. *Bather, Francis Arthur. Red House, Roehampton, Surrey, S.W.
1869. ‡Batten, John Winterbotham. 35 Palace Gardens-terrace, Kensington, London, W.
1863. §Bauerman, H., F.G.S. 41 Acre-lane, Brixton, London, S.W.
1861. ‡Baxendell, Joseph, F.R.A.S. 108 Stock-street, Manchester.
1867. ‡Baxter, Edward. Hazel Hall, Dundee.
1867. ‡Baxter, John B. Craig Tay House, Dundee.
1867. ‡Baxter, The Right Hon. William Edward, M.P. Ashcliffe, Dundee.
1868. ‡Bayes, William, M.D. 58 Brook-street, London, W.
1851. *Bayley, George. 16 London-street, Fenchurch-street, London, E.C.
1866. ‡Bayley, Thomas. Lenton, Nottingham.
Bayly, John. Seven Trees, Plymouth.
1875. *Bayly, Robert. Torr-grove, near Plymouth.
1876. *Baynes, Robert E., M.A. Christ Church, Oxford.
Bazley, Thomas Sebastian, M.A. Hatherop Castle, Fairford, Gloucestershire.
1860. *Beale, Lionel S., M.D., F.R.S., Professor of Pathological Anatomy in King's College. 61 Grosvenor-street, London, W.
1882. §Beamish, Captain A.W., R.E. Cranbury-terrace, Southampton.
1872. ‡Beanes, Edward, F.C.S. Moatlands, Paddock Wood, Brenchley, Kent.
1870. ‡Beard, Rev. Charles. 13 South-hill-road, Toxteth Park, Liverpool.
*Beatson, William. Ash Mount, Rotherham.
1855. *Beaufort, W. Morris, F.R.A.S., F.R.G.S., F.M.S., F.S.S. 18 Piccadilly, London, W.
1861. *Beaumont, Rev. Thomas George. Chelmondiston Rectory, Ipswich.
1871. *Beazley, Lieut.-Colonel George G., F.R.G.S. Army and Navy Club, Pall Mall, London, S.W.
1859. *Beck, Joseph, F.R.A.S. 68 Cornhill, London, E.C.
1864. §Becker, Miss Lydia E. 155 Shrewsbury-street, Whalley Range, Manchester.
1860. ‡Beckles, Samuel H., F.R.S., F.G.S. 9 Grand-parade, St. Leonard's-on-Sea.
1866. ‡Beddard, James. Derby-road, Nottingham.
1870. §Beddoe, John, M.D., F.R.S. Clifton, Bristol.
1858. ‡Bedford, James. Headingley, near Leeds.
1878. ‡Bedson, P. Phillips, D.Sc. Bradford House, Manchester.
1873. ‡Behrens, Jacob. Springfield House, North-parade, Bradford, Yorkshire.
1874. ‡Belcher, Richard Boswell. Blockley, Worcestershire.
1873. ‡Bell, A. P. Royal Exchange, Manchester.
1871. §Bell, Charles B. 6 Spring-bank, Hull.
Bell, Frederick John. Woodlands, near Maldon, Essex.
1859. ‡Bell, George. Windsor-buildings, Dumbarton.
1860. ‡Bell, Rev. George Charles, M.A. Marlborough College, Wilts.
1855. ‡*Bell, Capt. Henry. Chalfont Lodge, Cheltenham.*
1880. §Bell, Henry Oswin. 13 Northumberland-terrace, Tynemouth.
1879. ‡Bell, Henry S. Kenwood Bank, Sharrow, Sheffield.
1862. *Bell, Isaac Lowthian, F.R.S., F.C.S., M.I.C.E. Rounton Grange, Northallerton.
1875. ‡Bell, James, F.C.S. The Laboratory, Somerset House, London, W.C.
1871. *Bell, J. Carter, F.C.S. Kersal Clough, Higher Broughton, Manchester.

Year of Election.

1853. ‡Bell, John Pearson, M.D. Waverley House, Hull.
1864. ‡Bell, R. Queen's College, Kingston, Canada.
1876. ‡*Bell, R. Bruce. 2 Clifton-place, Glasgow.*
1863. *Bell, Thomas. Palazo Vitoria, Bilbao, Spain.
1867. ‡Bell, Thomas. Belmont, Dundee.
1882. §Bell, W. Alexander, B.A. Dullwood, Redhill, Surrey.
1875. ‡Bell, William. Witford House, Briton Ferry, Glamorganshire.
1842. Bellhouse, Edward Taylor. Eagle Foundry, Manchester.
Bellingham, Sir Alan. Castle Bellingham, Ireland.
1882. §Bellingham, William. 2 Edinburgh Mansions, Victoria-street, London, S.W.
1864. *Bendyshe, T. 3 Sea View-terrace, Margate.
1870. ‡Bennett, Alfred W., M.A., B.Sc., F.L.S. 6 Park Village East, Regent's Park, London, N.W.
1836. §Bennett, Henry. Bedminster, Bristol.
1881. §Bennett, John R. Bedminster, Bristol.
1881. ‡Bennett, Rev. S. H., M.A. St. Mary's Vicarage, Bishophill Junior, York.
1870. *Bennett, William. Heysham Tower, Lancaster.
1870. *Bennett, William, jun. Oak Hill Park, Old Swan, near Liverpool.
1852. *Bennoch, Francis, F.S.A. 5 Tavistock-square, London, W.C.
1848. ‡Benson, Starling, F.G.S. Gloucester-place, Swansea.
1870. ‡Benson, W. Alresford, Hants.
1863. ‡Benson, William. Fourstones Court, Newcastle-on-Tyne.
1848. ‡Bentham, George, F.R.S., F.R.G.S., F.L.S. 25 Wilton-place, Knightsbridge, London, S.W.
1842. Bentley, John. 2 Portland-place, London, W.
1863. §Bentley, Robert, F.L.S., Professor of Botany in King's College, London. 38 Penywern-road, Earl's Court, London, S.W.
1875. ‡*Beor, Henry R. Scientific Club, Savile-row, London, W.*
1876. ‡Bergius, Walter C. 9 Loudon-terrace, Hillhead, Glasgow.
1868. ‡Berkeley, Rev. M. J., M.A., F.R.S., F.L.S. Sibbertoft, Market Harborough.
1863. ‡Berkley, C. Marley Hill, Gateshead, Durham.
1881. ‡Berkley, H. Rorke. Prestwich, Manchester.
1848. ‡Berrington, Arthur V. D. Woodlands Castle, near Swansea.
1870. ‡Berwick, George, M.D. 36 Fawcett-street, Sunderland.
1862. ‡Besant, William Henry, M.A., F.R.S. St. John's College, Cambridge.
1865. *Bessemer, Sir Henry, F.R.S. Denmark Hill, London, S.E.
1882. §Bessemer, Henry, jun. Mount House, Hythe, Southampton.
1858. ‡Best, William. Leydon-terrace, Leeds.
Bethune, Admiral, C.B., F.R.G.S. Balfour, Fifeshire.
1876. *Bettany, G. T., M.A., B.Sc., Lecturer on Botany at Guy's Hospital, London. 2 Eckington-villas, Ashbourne-grove, East Dulwich, S.E.
1880. *Bevan, Rev. James Oliver, M.A. 72 Beaufort-road, Edgbaston, Birmingham.
1859. ‡Beveridge, Robert, M.B. 36 King-street, Aberdeen.
1874. *Bevington, James B. Merle Wood, Sevenoaks.
1863. ‡Bewick, Thomas John, F.G.S. Haydon Bridge, Northumberland.
*Bickerdike, Rev. John, M.A. Shireshead Vicarage, Garstang.
1870. ‡Bickerton, A.W., F.C.S. Christchurch, Canterbury, New Zealand.
1863. ‡Bigger, Benjamin. Gateshead, Durham.
1882. §Biggs, C. H. W., F.C.S. 1 Bloomfield, Bromley, Kent.
1864. ‡Biggs, Robert. 16 Green Park, Bath.
Bilton, Rev. William, M.A., F.G.S. United University Club, Suffolk-street, London, S.W.

Year of Election.

1877. ‡*Binder, W. J., B.A. Barnsley.*
1881. ‡Binnie, Alexander R., F.G.S. Town Hall, Bradford, Yorkshire.
1873. ‡Binns, J. Arthur. Manningham, Bradford, Yorkshire.
1879. ‡Binns, E. Knowles, F.R.G.S. 216 Heavygate-road, Sheffield.
Birchall, Edwin, F.L.S. Douglas, Isle of Man.
Birchall, Henry. College House, Bradford.
1880. §Bird, Henry, F.C.S. South Down, near Devonport.
1866. *Birkin, Richard. Aspley Hall, near Nottingham.
*Birks, Rev. Thomas Rawson, M.A., Professor of Moral Philosophy in the University of Cambridge. 6 Salisbury-villas, Cambridge.
1871. *BISCHOF, GUSTAV. 4 Hart-street, Bloomsbury, London, W.C.
1868. ‡Bishop, John. Thorpe Hamlet, Norwich.
1866. ‡Bishop, Thomas. Bramcote, Nottingham.
1877. ‡BLACHFORD, The Right Hon. Lord, K.C.M.G. Cornwood, Ivybridge.
1881. §Black, W. J., F.R.C.S.E. Caledonian United Service Club, Edinburgh.
1869. ‡Blackall, Thomas. 13 Southernhay, Exeter.
1834. Blackburn, Bewicke. 14 Victoria-road, Kensington, London, W.
1876. ‡Blackburn, Hugh, M.A. Roshven, Fort William, N.B.
Blackburne, Rev. John, M.A. Yarmouth, Isle of Wight.
Blackburne, Rev. John, jun., M.A. Rectory, Horton, near Chippenham.
1877. ‡Blackie, J. Alexander. 17 Stanhope-street, Glasgow.
1859. ‡Blackie, John Stewart, M.A., Professor of Greek in the University of Edinburgh.
1876. ‡Blackie, Robert. 7 Great Western-terrace, Glasgow.
1855. *BLACKIE, W. G., Ph.D., F.R.G.S. 17 Stanhope-street, Glasgow.
1870. ‡Blackmore, W. Founder's-court, Lothbury, London, E.C.
1878. §Blair, Matthew. Oakshaw, Paisley.
1863. ‡Blake, C. Carter, D.Sc. Westminster Hospital School of Medicine, Broad Sanctuary, Westminster, S.W.
1849. *BLAKE, HENRY WOLLASTON, M.A., F.R.S., F.R.G.S. 8 Devonshire-place, Portland-place, London, W.
1846. *Blake, William. Bridge House, South Petherton, Somerset.
1878. ‡Blakeney, Rev. Canon, M.A., D.D. The Vicarage, Sheffield.
1861. §Blakiston, Matthew, F.R.G.S. Free Hills, Burledon, Hants.
1881. §Blamires, Thomas H. Close Hill, Lockwood, near Huddersfield.
1869. ‡Blanford, W. T., F.R.S., F.G.S., F.R.G.S. Arts Club, Hanover-square, London, W.
*BLOMEFIELD, Rev. LEONARD, M.A., F.L.S., F.G.S. 19 Belmont, Bath.
1880. §Bloxam, G. W., M.A., F.L.S. 44 Dacre-park, Lee, Kent.
1870. ‡Blundell, Thomas Weld. Ince Blundell Hall, Great Crosby, Lancashire.
1859. ‡Blunt, Sir Charles, Bart. Heathfield Park, Sussex.
1859. ‡Blunt, Captain Richard. Bretlands, Chertsey, Surrey.
Blyth, B. Hall. 135 George-street, Edinburgh.
1858. *Blythe, William. Holland Bank, Church, near Accrington.
1867. ‡Blyth-Martin, W. Y. Blyth House, Newport, Fife.
1870. ‡Boardman, Edward. Queen-street, Norwich.
1859. *BOHN, HENRY G., F.L.S., F.R.A.S., F.R.G.S., F.S.S. North End House, Twickenham.
1871. ‡Bohn, Mrs. North End House, Twickenham.
1881. ‡Bojanowski, Dr. Victor de, Consul-General for Germany. 27 Finsbury-circus, London, E.C.
1859. ‡Bolster, Rev. Prebendary John A. Cork.

Year of Election.

1876. ‡Bolton, J. C. Carbrook, Stirling.
Bolton, R. L. Laurel Mount, Aigburth-road, Liverpool.
1866. ‡Bond, Banks. Low Pavement, Nottingham.
Bond, Henry John Hayes, M.D. Cambridge.
1871. §BONNEY, Rev. THOMAS GEORGE, M.A., F.R.S., F.S.A., F.G.S., Professor of Geology in University College, London. (SECRETARY.) 23 Denning-road, Hampstead, London, N.W.
1866. ‡Booker, W. H. Cromwell-terrace, Nottingham.
1861. ‡Booth, James. Elmfield, Rochdale.
1861. *Booth, William. Hollybank, Cornbrook, Manchester.
1876. ‡Booth, Rev. William H. Yardley, Birmingham.
1880. §Boothroyd, Samuel. Warley House, Southport.
1861. *Borchardt, Louis, M.D. Barton Arcade, Manchester.
1849. ‡Boreham, William W., F.R.A.S. The Mount, Haverhill, Newmarket.
1876. *Borland, William. 260 West George-street, Glasgow.
1882. §Borns, Henry, Ph.D., F.C.S. 7 Goldney-road, Paddington, London, W.
1876. *Bosanquet, R. H. M., M.A., F.C.S., F.R.A.S. St. John's College, Oxford.
*Bossey, Francis, M.D. Mayfield, Oxford-road, Redhill, Surrey.
1881. §Bothamley, Charles H. Yorkshire College, Leeds.
1867. §Botly, William, F.S.A. Salisbury House, Hamlet-road, Upper Norwood, London, S.E.
1872. ‡Bottle, Alexander. Dover.
1868. ‡Bottle, J. T. 28 Nelson-road, Great Yarmouth.
1871. *BOTTOMLEY, JAMES THOMSON, M.A., F.R.S.E., F.C.S. 2 Eton-terrace, Hillhead, Glasgow.
Bottomley, William. Southampton-place, Reading.
1876. ‡Bottomley, William, jun. 6 Rokeley-terrace, Hillhead, Glasgow.
1870. ‡Boult, Swinton. 1 Dale-street, Liverpool.
1868. ‡Boulton, W. S. Norwich.
1866. §BOURNE, STEPHEN, F.S.S. Abberley, Wallington, Surrey.
1872. ‡Bovill, William Edward. 29 James-street, Buckingham-gate, London, S.W.
1870. ‡Bower, Anthony. Bowersdale, Seaforth, Liverpool.
1881. *Bower, F. O. Elmscroft, Ripon, Yorkshire.
1867. ‡Bower, Dr. John. Perth.
1856. *Bowlby, Miss F. E. 23 Lansdowne-parade, Cheltenham.
1880. ‡Bowly, Christopher. Cirencester.
1863. ‡Bowman, R. Benson. Newcastle-on-Tyne.
BOWMAN, WILLIAM, F.R.S., F.R.C.S. 5 Clifford-street, London, W.
1869. ‡Bowring, Charles T. Elmsleigh, Prince's-park, Liverpool.
1863. ‡Boyd, Edward Fenwick. Moor House, near Durham.
1871. ‡Boyd, Thomas J. 41 Moray-place, Edinburgh.
1865. ‡BOYLE, The Very Rev. G. D., M.A., Dean of Salisbury. The Deanery, Salisbury.
1872. *BRABROOK, E. W., F.S.A., Dir. A.I. 28 Abingdon-street, Westminster, S.W.
1869. *Braby, Frederick, F.G.S., F.C.S. Bushey Lodge, Teddington, Middlesex.
1870. ‡*Brace, Edmund. 3 Spring-gardens, Kelvinside, Glasgow.*
Bracebridge, Charles Holt, F.R.G.S. The Hall, Atherstone, Warwickshire.
1880. §Bradford, H. Stretton House, Walters-road, Swansea.
Bradshaw, William. Slade House, Green-walk, Bowdon, Cheshire.
1857. *Brady, Cheyne, M.R.I.A. Trinity Vicarage, West Bromwich.

Year of Election.

Brady, Daniel F., M.D. 5 Gardiner's-row, Dublin.
1863. ‡Brady, George S., M.D., F.R.S., F.L.S., Professor of Natural History in the College of Physical Science, Newcastle-on-Tyne. 22 Fawcett-street, Sunderland.
1862. §Brady, Henry Bowman, F.R.S., F.L.S., F.G.S. Hillfield, Gateshead.
1880. *Brady, Rev. Nicholas, M.A. Wennington, Essex.
1875. ‡Bragge, William, F.S.A., F.G.S. Shirle Hill, Birmingham.
1864. §Braham, Philip, F.C.S. 6 George-street, Bath.
1870. ‡Braidwood, Dr. Delemere-terrace, Birkenhead.
1879. ‡Bramley, Herbert. Claremont-crescent, Sheffield.
1865. §Bramwell, Sir Frederick J., F.R.S., M.I.C.E. 37 Great George-street, London, S.W.
1872. ‡Bramwell, William J. 17 Prince Albert-street, Brighton.
1867. ‡Brand, William. Milnefield, Dundee.
1861. *Brandreth, Rev. Henry. Dickleburgh Rectory, Scole, Norfolk.
1852. ‡Brazier, James S., F.C.S., Professor of Chemistry in Marischal College and University of Aberdeen.
1857. ‡*Brazill, Thomas. 12 Holles-street, Dublin.*
1869. *Breadalbane, The Right Hon. the Earl of. Taymouth Castle, N.B.; and Carlton Club, Pall Mall, London, S.W.
1868. ‡Bremridge, Elias. 17 Bloomsbury-square, London, W.C.
1877. ‡Brent, Francis. 19 Clarendon-place, Plymouth.
1882. *Bretherton, C.E. 54 Old Broad-street, London, E.C.
1881. *Brett, Alfred Thomas, M.D. Watford House, Watford.
1866. ‡Brettell, Thomas (Mine Agent). Dudley.
1875. ‡Briant, T. Hampton Wick, Kingston-on-Thames.
1867. ‡Bridgman, William Kenceley. 69 St. Giles's-street, Norwich.
1870. *Bridson, Joseph R. Belle Isle, Windermere.
1870. ‡Brierley, Joseph, C.E. New Market-street, Blackburn.
1879. ‡Brierley, Morgan. Denshaw House, Saddleworth.
1870. *Brigg, John. Broomfield, Keighley, Yorkshire.
1866. *Briggs, Arthur. Cragg Royd, Rawdon, near Leeds.
1863. *Bright, Sir Charles Tilston, C.E., F.G.S., F.R.G.S., F.R.A.S. 20 Bolton-gardens, London, S.W.
1870. ‡Bright, H. A., M.A., F.R.G.S. Ashfield, Knotty Ash.
Bright, The Right Hon. John, M.P. Rochdale, Lancashire.
1868. ‡Brine, Captain Lindesay, F.R.G.S. United Service Club, Pall Mall, London, S.W.
1879. ‡Brittain, Frederick. Taptonville-crescent, Sheffield.
1879. *Brittain, W. H. Storth Oaks, Ranmoor, Sheffield.
1878. ‡Britten, James, F.L.S. Department of Botany, British Museum, London, W.C.
1859. *Brodhurst, Bernard Edward, F.R.C.S., F.L.S. 20 Grosvenor-street, Grosvenor-square, London, W.
1865. ‡Brodie, Rev. Peter Bellinger, M.A., F.G.S. Rowington Vicarage, near Warwick.
1853. ‡*Bromby, J. H., M.A. The Charter House, Hull.*
1878. *Brook, George, F.L.S. Fernbrook, Huddersfield, Yorkshire.
1880. ‡Brook, G. B. Brynsyfi, Swansea.
1881. §Brook, Robert G. Rowen-street, St. Helen's, Lancashire.
1855. ‡Brooke, Edward. Marsden House, Stockport, Cheshire.
1864. *Brooke, Rev. J. Ingham. Thornhill Rectory, Dewsbury.
1855. ‡Brooke, Peter William. Marsden House, Stockport, Cheshire.
1878. ‡Brooke, Sir Victor, Bart., F.L.S. Colebrook, Brookeborough, Co. Fermanagh.
1863. ‡Brooks, John Crosse. Wallsend, Newcastle-on-Tyne.

Year of
Election.

1846. *Brooks, Thomas. Cranshaw Hall, Rawtenstall, Manchester.
Brooks, William. Ordfall Hill, East Retford, Nottinghamshire.
1847. ‡Broome, C. Edward, F.L.S. Elmhurst, Batheaston, near Bath.
1863. *Brown, Alexander Crum, M.D., F.R.S. L. & E., F.C.S., Professor of Chemistry in the University of Edinburgh. 8 Belgrave-crescent, Edinburgh.
1867. ‡Brown, Charles Gage, M.D. 88 Sloane-street, London, S.W.
1855. ‡Brown, Colin. 192 Hope-street, Glasgow.
1871. ‡Brown, David. 93 Abbey-hill, Edinburgh.
1863. *Brown, Rev. Dixon. Unthank Hall, Haltwhistle, Carlisle.
1881. ‡Brown, Frederick D. 26 St. Giles's-street, Oxford.
1870. §Brown, Horace T. 47 High-street, Burton-on-Trent.
Brown, Hugh. Broadstone, Ayrshire.
1870. *Brown, J. Campbell, D.Sc., F.C.S. Royal Infirmary School of Medicine, Liverpool.
1876. §Brown, John. Osborne Park, Belfast.
1881. *Brown, John, M.D. 66 Bank-parade, Burnley, Lancashire.
1882. §Brown, John. Swiss Cottage, Park-valley, Nottingham.
1882. *Brown, Mrs. Mary. Burnley, Lancashire.
1859. ‡Brown, Rev. John Crombie, LL.D., F.L.S. Berwick-on-Tweed.
1874. ‡Brown, John S. Edenderry, Shaw's Bridge, Belfast.
1863. ‡Brown, Ralph. Lambton's Bank, Newcastle-on-Tyne.
1871. ‡Brown, Robert, M.A., Ph.D., F.L.S., F.R.G.S. Ferslev, Rydal-road, Streatham, London, S.W.
1868. ‡Brown, Samuel. Grafton House, Swindon, Wilts.
*Brown, Thomas. Evesham Lawn, Pittville, Cheltenham.
*Brown, William. 11 Maiden-terrace, Dartmouth Park, London, N.
1855. ‡Brown, William. 33 Berkeley-terrace, Glasgow.
1850. ‡Brown, William, F.R.S.E. 25 Dublin-street, Edinburgh.
1865. ‡Brown, William. 41a New-street, Birmingham.
1879. ‡Browne, J. Crichton, M.D., LL.D., F.R.S.E. 7 Cumberland-terrace, Regent's Park, London, N.W.
1866. *Browne, Rev. J. H. Lowdham Vicarage, Nottingham.
1862. *Browne, Robert Clayton, jun., B.A. Browne's Hill, Carlow, Ireland.
1872. ‡Browne, R. Mackley, F.G.S. Northside, St. John's, Sevenoaks, Kent.
1875. ‡Browne, Walter R., M.A., C.E. 38 Belgrave-road, London, S.W.
1865. *Browne, William, M.D. The Friary, Lichfield.
1865. ‡Browning, John, F.R.A.S. 63 Strand, London, W.C.
1855. ‡Brownlee, James, jun. 30 Burnbank-gardens, Glasgow.
1863. *Brunel, H. M. 23 Delahay-street, Westminster, S.W.
1863. ‡Brunel, J. 23 Delahay-street, Westminster, S.W.
1875. *Brunlees, James, F.R.S.E., F.G.S., M.I.C.E. 5 Victoria-street, Westminster, S.W.
1875. ‡Brunlees, John. 5 Victoria-street, Westminster, S.W.
1868. ‡Brunton, T. Lauder, M.D., F.R.S. 50 Welbeck-street, London, W.
1878. §Brutton, Joseph. Yeovil.
1877. ‡Bryant, George. 82 Claverton-street, Pimlico, London, S.W.
1875. ‡Bryant, G. Squier. 15 White Ladies'-road, Clifton, Bristol.
1875. ‡Bryant, Miss S. A. The Castle, Denbigh.
1861. ‡*Bryce, James. York-place, Higher Broughton, Manchester.*
Bryce, Rev. R. J., LL.D. Fitzroy-avenue, Belfast.
1859. ‡Bryson, William Gillespie. Cullen, Aberdeen.
1867. ‡Buccleuch and Queensberry, His Grace the Duke of, K.G., D.C.L., F.R.S. L. & E., F.L.S. Whitehall-gardens, London, S.W.; and Dalkeith House, Edinburgh.

Year of Election.

1871. §BUCHAN, ALEXANDER, M.A., F.R.S.E., Sec. Scottish Meteorological Society. 72 Northumberland-street, Edinburgh.
1867. ‡Buchan, Thomas. Strawberry Bank, Dundee.
Buchanan, Archibald. Catrine, Ayrshire.
Buchanan, D. C. Poulton-cum-Seacombe, Cheshire.
1881. §Buchanan, J. H., M.D. Sowerby, Thirsk.
1871. ‡BUCHANAN, JOHN YOUNG. 10 Moray-place, Edinburgh.
1864. §BUCKLE, Rev. GEORGE, M.A. The Rectory, Weston-super-Mare.
1865. *Buckley, Henry. 27 Wheeley's-road, Edgbaston, Birmingham.
1848. *BUCKMAN, Professor JAMES, F.L.S., F.G.S. Bradford Abbas, Sherborne, Dorsetshire.
1880. §Buckney, Thomas, F.R.A.S. Little Thurlow, Suffolk.
1869. ‡Bucknill, J. C., M.D., F.R.S. 39 Wimpole-street, London, W.
1851. *BUCKTON, GEORGE BOWDLER, F.R.S., F.L.S., F.C.S. Weycombe, Haslemere, Surrey.
1848. *BUDD, JAMES PALMER. Ystalyfera Iron Works, Swansea.
1875. §Budgett, Samuel. Cotham House, Bristol.
1871. ‡Bulloch, Matthew. 4 Bothwell-street, Glasgow.
1881. ‡Bulmer, T. P. Mount-villas, York.
1845. *BUNBURY, Sir CHARLES JAMES FOX, Bart., F.R.S., F.L.S., F.G.S., F.R.G.S. Barton Hall, Bury St. Edmunds.
1865. ‡Bunce, John Mackray. 'Journal' Office, New-street, Birmingham.
1863. §Bunning, T. Wood. Institute of Mining and Mechanical Engineers, Newcastle-on-Tyne.
1842. *Burd, John. 5 Gower-street, London, W.C.
1875. ‡Burder, John, M.D. 7 South-parade, Bristol.
1869. ‡Burdett-Coutts, Baroness. 1 Stratton-street, Piccadilly, London, W.
1881. §Burdett-Coutts, W. L. A. B. 1 Stratton-street, Piccadilly, London, W.
1874. ‡Burdon, Henry, M.D. Clandeboye, Belfast.
1876. ‡Burnet, John. 14 Victoria-crescent, Dowanhill, Glasgow.
1859. ‡Burnett, Newell. Belmont-street, Aberdeen.
1877. ‡Burns, David, C.E. Alston, Carlisle.
1881. ‡Burnure, William. Harlow, Essex.
1881. §Burroughs, S. M. 7 Snow-hill, London, E.C.
1860. ‡Burrows, Montague, M.A., Professor of Modern History, Oxford.
1877. ‡Burt, J. Kendall. Kendal.
1874. ‡Burt, Rev. J. T. Broadmoor, Berks.
1866. *BURTON, FREDERICK M., F.G.S. Highfield, Gainsborough.
1899. ‡*Bury, Percy B. Cambridge.*
1864. ‡Bush, W. 7 Circus, Bath.
Bushell, Christopher. Royal Assurance-buildings, Liverpool.
1855. *BUSK, GEORGE, F.R.S., F.L.S., F.G.S. 32 Harley-street, Cavendish-square, London, W.
1878. ‡BUTCHER, J. G., M.A. 22 Collingham-place, London, S.W.
1872. ‡Buxton, Charles Louis. Cromer, Norfolk.
1870. ‡Buxton, David, Ph.D. 298 Regent-street, London, W.
1868. ‡Buxton, S. Gurney. Catton Hall, Norwich.
1881. ‡Buxton, Sydney. 7 Grosvenor-crescent, London, S.W.
1872. ‡Buxton, Sir T. Fowell, Bart. Warlies, Waltham Abbey, Essex.
1854. ‡BYERLEY, ISAAC, F.L.S. Seacombe, Liverpool.
1852. ‡Byrne, Very Rev. James. Ergenagh Rectory, Omagh.
1875. ‡Byrom, W. Ascroft, F.G.S. 31 King-street, Wigan.

1863. ‡Cail, Richard. Beaconsfield, Gateshead.

Year of Election.

1858. *Caine, Rev. William, M.A. Christ Church Rectory, Denton, near Manchester.
1863. ‡Caird, Edward. Finnart, Dumbartonshire.
1876. ‡Caird, Edward B. 8 Scotland-street, Glasgow.
1861. *Caird, James Key. 8 Magdalene-road, Dundee.
1855. *Caird, James Tennant. Belleaire, Greenock.
1875. ‡Caldicott, Rev. J. W., D.D. The Grammar School, Bristol.
1877. ‡Caldwell, Miss. 2 Victoria-terrace, Portobello, Edinburgh.
1868. ‡Caley, A. J. Norwich.
1868. ‡Caley, W. Norwich.
1857. ‡Callan, Rev. N. J., Professor of Natural Philosophy in Maynooth College.
1853. ‡Calver, Captain E. K., R.N., F.R.S. The Grange, Redhill, Surrey.
1876. ‡Cameron, Charles, M.D., LL.D., M.P. 1 Huntly-gardens, Glasgow.
1857. ‡CAMERON, CHARLES A., M.D. 15 Pembroke-road, Dublin.
1870. ‡Cameron, John, M.D. 17 Rodney-street, Liverpool.
1881. ‡Cameron, Major-General, C.B. 3 Driffield-terrace, York.
1874. *CAMPBELL, Sir GEORGE, K.C.S.I., M.P., D.C.L., F.R.G.S., F.S.S. 17 Southwell-gardens, South Kensington, London, S.W.; and Edenwood, Cupar, Fife.
Campbell, Sir Hugh P. H., Bart. 10 Hill-street, Berkeley-square, London, W.; and Marchmont House, near Dunse, Berwickshire.
1876. ‡Campbell, James A. 3 Claremont-terrace, Glasgow.
Campbell, John Archibald. M.D., F.R.S.E. Albyn-place, Edinburgh.
1872. ‡CAMPBELL, Rev. J. R., D.D. 5 Eldon-place, Manningham-lane, Bradford, Yorkshire.
1859. ‡Campbell, William. Dunmore, Argyllshire.
1871. ‡Campbell, William Hunter, LL.D. Georgetown, Demerara, British Guiana. (Messrs. Ridgway & Sons, 2 Waterloo-place, London, S.W.)
CAMPBELL-JOHNSTON, ALEXANDER ROBERT, F.R.S. 84 St. George's-square, London, S.W.
1876. §Campion, Frank, F.G.S., F.R.G.S. The Mount, Duffield-road, Derby.
1862. *CAMPION, Rev. WILLIAM M., D.D. Queen's College, Cambridge.
1882. §Candy, F. H. 71 High-street, Southampton.
1880. ‡Capper, Robert. Cwm Donkin, Swansea.
1873. *Carbutt, Edward Hamer, M.P., C.E. 19 Hyde Park-gardens, London, W.
*Carew, William Henry Pole. Antony, Torpoint, Devonport.
1877. ‡Carkeet, John, C.E. 3 St. Andrew's-place, Plymouth.
1876. ‡Carlile, Thomas. 5 St. James's-terrace, Glasgow.
CARLISLE, The Right Rev. HARVEY GOODWIN, D.D., Lord Bishop of Carlisle.
1861. ‡Carlton, James. Mosley-street, Manchester.
1867. ‡Carmichael, David (Engineer). Dundee.
1867. ‡Carmichael, George. 11 Dudhope-terrace, Dundee.
1876. ‡Carmichael, Neil, M.D. 22 South Cumberland-street, Glasgow.
1871. ‡CARPENTER, CHARLES. Brunswick-square, Brighton.
1871. *CARPENTER, P. HERBERT, M.A. Eton College, Windsor.
1854. ‡Carpenter, Rev. R. Lant, B.A. Bridport.
1845. ‡CARPENTER, WILLIAM B., C.B., M.D., LL.D., F.R.S., F.L.S., F.G.S. 56 Regent's Park-road, London, N.W.
1872. §CARPENTER, WILLIAM LANT, B.A., B.Sc., F.C.S. 36 Craven-park, Harlesden, London, N.W.
?7. ‡CARRUTHERS, WILLIAM, F.R.S., F.L.S., F.G.S. British Museum, London, W.C.

Year of Election.

1861. *Carson, Rev. Joseph, D.D., M.R.I.A. 18 Fitzwilliam-place, Dublin.
1857. ‡CARTE, ALEXANDER, M.D. Museum of Science and Art, Dublin.
1868. ‡Carteighe, Michael, F.C.S. 172 New Bond-street, London, W.
1866. ‡Carter, H. H. The Park, Nottingham.
1855. ‡Carter, Richard, C.E., F.G.S. Cockerham Hall, Barnsley, Yorkshire.
1870. ‡Carter, Dr. William. 62 Elizabeth-street, Liverpool.
1878. *Cartwright, E. Henry. Magherafelt Manor, Co. Derry.
1870. §Cartwright, Joshua, A.I.C.E., Borough Surveyor. Bury, Lancashire.
1862. ‡Carulla, Facundo, F.A.S.L. Care of Messrs. Daglish and Co., 8 Harrington-street, Liverpool.
1868. ‡Cary, Joseph Henry. Newmarket-road, Norwich.
1866. §Casella, L. P., F.R.A.S. The Lawns, Highgate, London, N.
1878. ‡Casey, John, LL.D., F.R.S., M.R.I.A., Professor of Higher Mathematics in the Catholic University of Ireland. 2 Iona-terrace, South Circular-road, Dublin.
1871. ‡Cash, Joseph. Bird-grove, Coventry.
1873. *Cash, William, F.G.S. 38 Elmfield-terrace, Saville Park, Halifax.
Castle, Charles. Clifton, Bristol.
1874. ‡Caton, Richard, M.D., Lecturer on Physiology at the Liverpool Medical School. 18A Abercromby-square, Liverpool.
1853. ‡*Cator, John B., Commander R.N.* 1 *Adelaide-street, Hull.*
1859. ‡Catto, Robert. 44 King-street, Aberdeen.
1849. ‡Cawley, Charles Edward. The Heath, Kirsall, Manchester.
1860. §CAYLEY, ARTHUR, LL.D., F.R.S., V.P.R.A.S., Sadlerian Professor of Mathemathics in the University of Cambridge. (PRESIDENT ELECT.) Garden House, Cambridge.
Cayley, Digby. Brompton, near Scarborough.
Cayley, Edward Stillingfleet. Wydale, Malton, Yorkshire.
1871. *Cecil, Lord Sackville. Hayes Common, Beckenham, Kent.
1879. §Chadburn, Alfred. Brincliffe Rise, Sheffield.
1870. ‡Chadburn, C. H. Lord-street, Liverpool.
1858. *Chadwick, Charles, M.D. Lynncourt, Broadwater Down, Tunbridge Wells.
1860. ‡CHADWICK, DAVID. The Poplars, Herne Hill, London, S.E.
1842. CHADWICK, EDWIN, C.B. Richmond, Surrey.
1859. ‡Chadwick, Robert. Highbank, Manchester.
1859. ‡Chalmers, John Inglis. Aldbar, Aberdeen.
1865. ‡CHAMBERLAIN, The Right Hon. J. H., M.P., F.R.S. Southbourne, Augustus-road, Birmingham.
1842. Chambers, George. High Green, Sheffield.
1868. ‡Chambers, W. O. Lowestoft, Suffolk.
1877. *CHAMPERNOWNE, ARTHUR, M.A., F.G.S. Dartington Hall, Totnes, Devon.
*Champney, Henry Nelson. 4 New-street, York.
1881. *Champney, John E. Woodlands, Halifax.
1865. ‡Chance, A. M. Edgbaston, Birmingham.
1865. *Chance, James T. 51 Prince's-gate, London, S.W.
1865. ‡Chance, Robert Lucas. Chad Hill, Edgbaston, Birmingham.
1861. *Chapman, Edward, M.A., F.L.S., F.C.S. Frewen Hall, Oxford.
1877. §Chapman, T. Algernon, M.D. Burghill, Hereford.
1866. ‡*Chapman, William. The Park, Nottingham.*
1871. ‡Chappell, William, F.S.A. Strafford Lodge, Oatlands Park, Weybridge Station.
1874. ‡Charles, John James, M.A., M.D. 11 Fisherwick-place, Belfast.

Year of Election.

1836. CHARLESWORTH, EDWARD, F.G.S. 277 Strand, London, W.C.
1874. ‡Charley, William. Seymour Hill, Dunmurry, Ireland.
1863. ‡Charlton, Edward, M.D. 7 Eldon-square, Newcastle-on-Tyne.
1866. ‡CHARNOCK, RICHARD STEPHEN, Ph.D., F.S.A., F.R.G.S. Junior Garrick Club, Adelphi-terrace, London, W.C.
Chatto, W. J. P. Union Club, Trafalgar-square, London, S.W.
1867. *Chatwood, Samuel, F.R.G.S. Irwell House, Drinkwater Park, Prestwich.
1864. ‡CHEADLE, W. B., M.A., M.D., F.R.G.S. 2 Hyde Park-place, Cumberland-gate, London, S.W.
1874. *Chermside, Lieutenant H. C., R.E. Care of Messrs. Cox & Co., Craig's-court, Charing Cross, London, S.W.
1879. *Chesterman, W. Broomsgrove-road, Sheffield.
1879. ‡Cheyne, Commander J. P., R.N. 1 Westgate-terrace, West Brompton, London, S.W.
1872. §CHICHESTER, The Right Hon. the Earl of. Stanmer House, Lewes.
CHICHESTER, The Right Rev. RICHARD DURNFORD, D.D., Lord Bishop of. Chichester.
1865. *Child, Gilbert W., M.A., M.D., F.L.S. Cowley House, Oxford.
1842. *Chiswell, Thomas. 17 Lincoln-grove, Plymouth-grove, Manchester.
1863. ‡Cholmeley, Rev. C. H. Dinton Rectory, Salisbury.
1882. §Chorley, George. Midhurst, Sussex.
1859. ‡Christie, John, M.D. 46 School-hill, Aberdeen.
1861. ‡Christie, Professor R. C., M.A. 7 St. James's-square, Manchester.
1875. *Christopher, George, F.C.S. 8 Rectory-grove, Clapham, London, S.W.
1876. *CHRYSTAL, G., M.A., Professor of Mathematics in the University of Edinburgh. 5 Belgrave-crescent, Edinburgh.
1870. §CHURCH, A. H., M.A., F.C.S., Professor of Chemistry to the Royal Academy of Arts, London. Shelsley, Ennerdale-road, Kew, Surrey.
1860. ‡Church, William Selby, M.A. St. Bartholomew's Hospital, London, E.C.
1881. §Churchill, Lord Alfred Spencer. 16 Rutland-gate, London, S.W.
1857. ‡Churchill, F., M.D. Ardtrea Rectory, Stewartstown, Co. Tyrone.
1882. §Churton, Frederick. Albion-place, Southampton.
1868. ‡Clabburn, W. H. Thorpe, Norwich.
1863. ‡Clapham, Henry. 5 Summerhill-grove, Newcastle-on-Tyne.
1869. *Clapp, Frederic. 2 East Southernhay, Exeter.
1857. ‡Clarendon, Frederick Villiers. 1 Belvidere-place, Mountjoy-square, Dublin.
1859. ‡Clark, David. Coupar Angus, Fifeshire.
1877. *Clark, F. J. Street, Somerset.
Clark, G. T. 44 Berkeley-square, London, W.
1876. ‡Clark, George W. Glasgow.
1876. ‡Clark, Dr. John. 138 Bath-street, Glasgow.
1861. ‡Clark, Latimer. 5 Westminster-chambers, Victoria-street, London, S.W.
1855. ‡Clark, Rev. William, M.A. Barrhead, near Glasgow.
1865. ‡Clarke, Rev. Charles. Charlotte-road, Edgbaston, Birmingham.
1875. ‡Clarke, Charles S. 4 Worcester-terrace, Clifton, Bristol.
Clarke, George. Mosley-street, Manchester.
1872. *CLARKE, HYDE. 32 St. George's-square, Pimlico, London, S.W.
1881. ‡Clarke, J. Edmund, B.A., B.Sc., F.G.S. 20 Bootham, York.
1875. ‡CLARKE, JOHN HENRY. 4 Worcester-terrace, Clifton, Bristol.
1861. *Clarke, John Hope. Lark Hill House, Edgeley, Stockport.
1877. ‡Clarke, Professor John W. University of Chicago, Illinois.

Year of Election.

1851. ‡CLARKE, JOSHUA, F.L.S. Fairycroft, Saffron Walden.
Clarke, Thomas, M.A. Knedlington Manor, Howden, Yorkshire.
1861. ‡Clay, Charles, M.D. 101 Piccadilly, Manchester.
*Clay, Joseph Travis, F.G.S. Rastrick, near Brighouse, Yorkshire.
1856. *Clay, Colonel William. The Slopes, Wallasea, Cheshire.
1866. ‡Clayden, P. W. 13 Tavistock-square, London, W.C.
1850. ‡CLEGHORN, HUGH, M.D., F.L.S. Stravithie, St. Andrews, Scotland.
1859. ‡Cleghorn, John. Wick.
1875. ‡Clegram, T. W. B. Saul Lodge, near Stonehouse, Gloucestershire.
1861. §CLELAND, JOHN, M.D., F.R.S., Professor of Anatomy in the University of Glasgow. 2 College, Glasgow.
1857. ‡*Clements, Henry. Dromin, Listowel, Ireland.*
‡*Clerk, Rev. D. M. Deverill, Warminster, Wiltshire.*
1873. §Cliff, John, F.G.S. Linnburn, Ilkley, near Leeds.
1861. *CLIFTON, R. BELLAMY, M.A., F.R.S., F.R.A.S., Professor of Experimental Philosophy in the University of Oxford. Portland Lodge, Park Town, Oxford.
Clonbrock, Lord Robert. Clonbrock, Galway.
1878. §Close, Rev. Maxwell H., F.G.S. 40 Lower Baggot-street, Dublin.
1873. ‡Clough, John. Bracken Bank, Keighley, Yorkshire.
1859. ‡Clouston, Rev. Charles. Sandwick, Orkney.
1861. *Clouston, Peter. 1 Park-terrace, Glasgow.
1863. *Clutterbuck, Thomas. Warkworth, Acklington.
1881. *Clutton, William James. The Mount, York.
1868. ‡Coaks, J. B. Thorpe, Norwich.
1855. *Coats, Sir Peter. Woodside, Paisley.
1855. *Coats, Thomas. Fergeslie House, Paisley.
Cobb, Edward. 13 Great Bedford-street, Bath.
1864. ‡COBBOLD, T. SPENCER, M.D., F.R.S., F.L.S., Professor of Botany and Helminthology in the Royal Veterinary College, London. 74 Portsdown-road, Maida Hill, London, W.
1864. *Cochrane, James Henry. Lochiar, Cork.
1861. *Coe, Rev. Charles C., F.R.G.S. Highfield, Manchester-road, Bolton.
1881. §Coffin, Walter Harris, F.C.S. 94 Cornwall-gardens, South Kensington, London, S.W.
1865. ‡Coghill, H. Newcastle-under-Lyme.
1876. ‡Colbourn, E. Rushton. 5 Marchmont-terrace, Hillhead, Glasgow.
1853. ‡Colchester, William, F.G.S. Springfield House, Ipswich.
1868. ‡Colchester, W. P. Bassingbourn, Royston.
1879. ‡Cole, Skelton. 387 Glossop-road, Sheffield.
1876. ‡Colebrooke, Sir T. E., Bart., M.P., F.R.G.S. 14 South-street, Park-lane, London, W.; and Abington House, Abington, N.B.
1860. ‡Coleman, J. J., F.C.S. 69 St. George's-place, Glasgow.
1878. ‡Coles, John, Curator of the Map Collection R.G.S. 1 Savile-row, London, W.
1854. *Colfox, William, B.A. Westmead, Bridport, Dorsetshire.
1857. ‡Colles, William, M.D. 21 Stephen's-green, Dublin.
1869. ‡Collier, W. F. Woodtown, Horrabridge, South Devon.
1854. ‡COLLINGWOOD, CUTHBERT, M.A., M.B., F.L.S. 2 Gipsy Hill-villas, Upper Norwood, Surrey, S.E.
1861. *Collingwood, J. Frederick, F.G.S. Anthropological Institute, 4 St. Martin's-place, London, W.C.
1865. *Collins, James Tertius. Churchfield, Edgbaston, Birmingham.
1876. ‡COLLINS, J. H., F.G.S. Rio Tinto Mines, Huelva, Spain.
1876. ‡Collins, William. 3 Park-terrace East, Glasgow.

Year of Election.

1868. *Colman, J. J., M.P. Carrow House, Norwich; and 108 Cannon-street, London, E.C.
1882. §Colmer, Joseph G. Office of the High Commissioner for Canada, 9 Victoria-chambers, London, S.W.
1870. ‡Coltart, Robert. The Hollies, Aigburth-road, Liverpool.
1874. ‡*Combe, James. Ormiston House, Belfast.*
*Compton, The Very Rev. Lord Alwyne, D.D., Dean of Worcester. The Deanery, Worcester.
1846. *Compton, Lord William. 145 Piccadilly, London, W.
1852. ‡Connal, Michael. 16 Lynedock-terrace, Glasgow.
1871. *Connor, Charles C. Hope House, College Park East, Belfast.
1881. §Conroy, Sir John, Bart. Arborfield, Reading, Berks.
1876. ‡Cook, James. 162 North-street, Glasgow.
1882. §Cooke, Major-General A. C., R.E., C.B., F.R.G.S., Director-General of the Ordnance Survey. Southampton.
1876. *Cooke, Conrad W., C.E. 5 Westminster-chambers, London, S.W.
1881. ‡Cooke, F. Bishophill, York.
1868. ‡Cooke, Rev. George H. Wanstead Vicarage, near Norwich.
Cooke, J. B. Cavendish-road, Birkenhead.
1868. ‡Cooke, M. C., M.A. 2 Grosvenor-villas, Upper Holloway, London, N.
1878. ‡Cooke, Samuel, M.A., F.G.S. Poona, Bombay.
1881. ‡Cooke, Thomas. Bishophill, York.
1859. *Cooke, William Henry, M.A., Q.C., F.S.A. 42 Wimpole-street, London, W.; and Rainthorpe Hall, Long Stratton.
1865. ‡Cooksey, Joseph. West Bromwich, Birmingham.
1863. ‡Cookson, N. C. Benwell Tower, Newcastle-on-Tyne.
1869. §Cooling, Edwin, F.R.G.S. Mile Ash, Derby.
1850. ‡Cooper, Sir Henry, M.D. 7 Charlotte-street, Hull.
Cooper, James. 58 Pembridge-villas, Bayswater, London, W.
1879. §Cooper, Thomas. Rose Hill, Rotherham, Yorkshire.
1868. ‡Cooper, W. J. The Old Palace, Richmond, Surrey.
1846. ‡Cooper, William White, F.R.C.S. 19 Berkeley-square, London, W.
1878. ‡Cope, Rev. S. W. Bramley, Leeds.
1868. ‡Copeman, Edward, M.D. Upper King-street, Norwich.
1881. ‡Copperthwaite, H. Holgate Villa, Holgate-lane, York.
1863. ‡Coppin, John. North Shields.
1842. Corbett, Edward. Ravenoak, Cheadle Hulme, Cheshire.
1855. ‡Corbett, Joseph Henry, M.D., Professor of Anatomy and Physiology in Queen's College, Cork.
1881. §Cordeaux, John. Great Cotes, Ulceby, Lincolnshire.
1870. *Corfield, W. H., M.A., M.D., F.C.S., F.G.S., Professor of Hygiène and Public Health in University College. 10 Bolton-row, Mayfair, London, W.
Cory, Rev. Robert, B.D., F.C.P.S. Stanground, Peterborough.
Cottam, George. 2 Winsley-street, London, W.
1857. ‡Cottam, Samuel. Brazenose-street, Manchester.
1855. ‡Cotterill, Rev. Henry, D.D., Bishop of Edinburgh. Edinburgh.
1874. *Cotterill, J. H., M.A., F.R.S., Professor of Applied Mechanics. Royal Naval College, Greenwich, S.E.
1864. ‡Cotton, General Frederick C., R.E., C.S.I. 13 Longridge-road, Earl's Court-road, London, S.W.
1869. ‡Cotton, William. Pennsylvania, Exeter.
1879. §Cottrill, Gilbert I. Shepton Mallett, Somerset.
1876. ‡Couper, James. City Glass Works, Glasgow.
1876. ‡Couper, James, jun. City Glass Works, Glasgow.
1874. ‡Courtauld, John M. Bocking Bridge, Braintree, Essex.
1834. ‡Cowan, Charles. 38 West Register-street, Edinburgh.

Year of Election.

1876. ‡Cowan, J. B., M.D. Helensburgh, N.B.
Cowan, John. Valleyfield, Pennycuick, Edinburgh.
1863. ‡Cowan, John A. Blaydon Burn, Durham.
1863. ‡Cowan, Joseph, jun. Blaydon, Durham.
1872. *Cowan, Thomas William. Comptons Lea, Horsham.
Cowie, The Very Rev. Benjamin Morgan, M.A., B.D., Dean of Manchester. The Deanery, Manchester.
1871. ‡Cowper, C. E. 3 Great George-street, Westminster, S.W.
1860. ‡Cowper, Edward Alfred, M.I.C.E. 6 Great George-street, Westminster, S.W.
1867. *Cox, Edward. 18 Windsor-street, Dundee.
1867. *Cox, George Addison. Beechwood, Dundee.
1867. ‡Cox, James. Clement Park, Lochee, Dundee.
1870. *Cox, James. 8 Falkner-square, Liverpool.
1882. §Cox, Thomas A., District Engineer of the S., P., and D. Railway. Lahore, Punjab. Care of Messrs. Grindlay & Co., Parliament-street, London, S.W.
1867. *Cox, Thomas Hunter. Duncarse, Dundee.
1867. ‡Cox, William. Foggley, Lochee, by Dundee.
1866. *Cox, William H. 150 Newhall-street, Birmingham.
1876. ‡Cramb, John. Larch Villa, Helensburgh, N.B.
1857. ‡*Crampton, Rev. Josiah. Nettlebeds, near Oxford.*
1879. §Crampton, Thomas Russell. 19 Ashley-place, London, S.W.
1858. ‡Cranage, Edward, Ph.D. The Old Hall, Wellington, Shropshire.
1876. ‡Crawford, Chalmond. Ridemon, Crosscar.
1871. *CRAWFORD AND BALCARRES, The Right Hon. the Earl of, LL.D., F.R.S., F.R.A.S. 47 Brook-street, London, W.
1871. *Crawford, William Caldwell, M.A. 27 Ziegelhaüser-strasse, Heidelberg.
1871. ‡Crawshaw, Edward. Burnley, Lancashire.
1870. *Crawshay, Mrs. Robert. Cathedine, Bwlch, Breconshire.
1879. ‡Creswick, Nathaniel. Handsworth Grange, near Sheffield.
1876. *Crewdson, Rev. George. St. George's Vicarage, Kendal.
CREYKE, The Venerable Archdeacon, M.A. Bolton Percy Rectory, Tadcaster.
1880. *Crisp, Frank, B.A., LL.B., F.L.S. 5 Lansdowne-road, Notting Hill, London, W.
1878. ‡Croke, John O'Byrne, M.A. The French College, Blackrock, Dublin.
1859. ‡Croll, A. A. 10 Coleman-street, London, E.C.
1857. ‡Crolly, Rev. George. Maynooth College, Ireland.
1866. ‡*Cronin, William. 4 Brunel-terrace, Nottingham.*
1870. ‡Crookes, Joseph. Marlborough House, Brook Green, Hammersmith, London, W.
1865. §CROOKES, WILLIAM, F.R.S., F.C.S. 7 Kensington Park-gardens, London, W.
1879. ‡Crookes, Mrs. 7 Kensington Park-gardens, London, W.
1855. ‡Cropper, Rev. John. Wareham, Dorsetshire.
1870. ‡Crosfield, C. J. 16 Alexandra-drive, Prince's Park, Liverpool.
1870. ‡Crosfield, William, sen. Annesley, Aigburth, Liverpool.
1870. *Crosfield, William, jun. 16 Alexandra-drive, Prince's Park, Liverpool.
1861. ‡Cross, Rev. John Edward, M.A. Appleby Vicarage, near Brigg.
1868. ‡Crosse, Thomas William. St. Giles's-street, Norwich.
1867. §CROSSKEY, Rev. H. W., LL.D., F.G.S. 28 George-road, Edgbaston, Birmingham.
1853. ‡Crosskill, William, C.E. Beverley, Yorkshire.
1870. *Crossley, Edward, F.R.A.S. Bemerside, Halifax.

Year of Election.

1871. ‡Crossley, Herbert. Broomfield, Halifax.
1866. *Crossley, Louis J., F.M.S. Moorside Observatory, near Halifax.
1882. §Crowley, Frederick. Ashdell, Alton, Hampshire.
1861. §Crowley, Henry. Trafalgar-road, Birkdale Park, Southport.
1863. ‡Cruddas, George. Elswick Engine Works, Newcastle-on-Tyne.
1860. ‡Cruickshank, John. Aberdeen.
1859. ‡Cruickshank, Provost. Macduff, Aberdeen.
1873. ‡Crust, Walter. Hall-street, Spalding.
Culley, Robert. Bank of Ireland, Dublin.
1878. ‡Culverwell, Joseph Pope. St. Lawrence Lodge, Sutton, Dublin.
1859. ‡Cumming, Sir A. P. Gordon, Bart. Altyre.
1874. ‡Cumming, Professor. 33 Wellington-place, Belfast.
1861. *Cunliffe, Edward Thomas. The Parsonage, Handforth, Manchester.
1861. *Cunliffe, Peter Gibson. The Elms, Handforth, Manchester.
1882. *Cunningham, Major Allan, R.E., A.I.C.E. Brompton Barracks, Chatham.
1877. ‡Cunningham, D. J., M.D. University of Edinburgh.
1852. ‡Cunningham, John. Macedon, near Belfast.
1869. ‡CUNNINGHAM, ROBERT O., M.D., F.L.S., Professor of Natural History in Queen's College, Belfast.
1855. ‡*Cunningham, William A. 2 Broadwalk, Buxton.*
1850. ‡Cunningham, Rev. William Bruce. Prestonpans, Scotland.
1866. ‡Cunnington, John. 68 Oakley-square, Bedford New Town, London, N.W.
1881. ‡Curley, T., C.E., F.G.S. Hereford.
1867. *Cursetjee, Manockjee, F.R.G.S., Judge of Bombay. Villa-Byculla, Bombay.
1857. ‡CURTIS, ARTHUR HILL, LL.D. 1 Hume-street, Dublin.
1878. ‡Curtis, William. Caramore, Sutton, Co. Dublin.
1881. §Cushing, Thomas, F.R.A.S. India Store Depôt, Belvedere-road, Lambeth, London, S.W.

1863. ‡*Daglish, John. Hetton, Durhom.*
1854. ‡Daglish, Robert, C.E. Orrell Cottage, near Wigan.
1863. ‡Dale, J. B. South Shields.
1865. †Dale, Rev. R. W. 12 Calthorpe-street, Birmingham.
1867. ‡Dalgleish, W. Dundee.
1870. ‡Dallinger, Rev. W. H., F.R.S. Sheffield College, Glossop-road, Sheffield.
Dalmahoy, James, F.R.S.E. 9 Forres-street, Edinburgh.
1859. ‡*Dalrymple, Charles Elphinstone. West Hall, Aberdeenshire.*
1859. ‡Dalrymple, Colonel. Troup, Scotland.
Dalton, Edward, LL.D., F.S.A. Dunkirk House, Nailsworth.
*Dalton, Rev. J. E., B.D. Seagrave, Loughborough.
1862. ‡DANBY, T. W., M.A., F.G.S. 1 Westbourne-terrace-road, London, W.
1859. ‡Dancer, J. B., F.R.A.S. Old Manor House, Ardwick. Manchester.
1876. ‡Dansken. John. 4 Eldon-terrace, Partickhill, Glasgow.
1849. *Danson, Joseph, F.C.S. Montreal, Canada.
1861. *DARBISHIRE, ROBERT DUKINFIELD, B.A., F.G.S. 26 George-street, Manchester.
1876. ‡Darling, G. Erskine. 247 West George-street, Glasgow.
1882. §DARWIN, FRANCIS, M.A., F.R.S., F.L.S. Down, Beckenham, Kent.
1881. *DARWIN, GEORGE HOWARD, M.A., F.R.S., F.R.A.S., Plumian Professor of Astronomy and Experimental Philosophy in the University of Cambridge. Trinity College, Cambridge.
1878. *Darwin, Horace. 66 Hills-road, Cambridge.

Year of Election.

1882. §Darwin, W. E., F.G.S. Bassett, Southampton.
1848. ‡DaSilva, Johnson. Burntwood, Wandsworth Common, London, S.W.
1878. ‡D'Aulmay, G. 22 Upper Leeson-street, Dublin.
1872. ‡Davenport, John T. 64 Marine Parade, Brighton.
1880. §Davey, Henry, C.E. Rupert Lodge, Grove-road, Headingley, Leeds.
1870. ‡Davidson, Alexander, M.D. 8 Peel-street, Toxteth Park, Liverpool.
1871. ‡Davidson, James. Newbattle, Dalkeith, N.B.
1859. ‡Davidson, Patrick. Inchmarlo, near Aberdeen.
1872. ‡DAVIDSON, THOMAS, F.R.S., F.G.S. 3 Leopold-road, Brighton.
1875. ‡Davies, David. 2 Queen's-square, Bristol.
1870. ‡Davies, Edward, F.C.S. Royal Institution, Liverpool.
1842. Davies-Colley, Dr. Thomas. Newton, near Chester.
1873. *Davis, Alfred. Parliament Mansions, London, S.W.
1870. *Davis, A. S. 12 Suffolk-square, Cheltenham.
1864. ‡DAVIS, CHARLES E., F.S.A. 55 Pulteney-street, Bath.
Davis, Rev. David, B.A. Lancaster.
1881. §Davis, George E. Dagmar Villa, Heaton Chapel, Stockport.
1882. §Davis Henry C. Berry Pomeroy, Springfield-road, Brighton.
1873. *DAVIS, JAMES W., F.G.S., F.S.A. Chevinedge, near Halifax.
1856. *DAVIS, Sir JOHN FRANCIS, Bart., K.C.B., F.R.S., F.R.G.S. 36 Royal York-crescent, Clifton, Bristol.
1859. *Davis, Richard, F.L.S. 9 St. Helen's-place, London, E.C.
1882. §Davis, W. H. Gloucester Lodge, Portswood, Southampton.
1873. ‡*Davis, William Samuel. 1 Cambridge-villas, Derby.*
1864. *Davison, Richard. Beverley-road, Great Driffield, Yorkshire.
1857. ‡DAVY, EDMUND W., M.D. Kimmage Lodge, Roundtown, near Dublin.
1869. ‡Daw, John. Mount Radford, Exeter.
1869. ‡Daw, R. M. Bedford-circus, Exeter.
1860. *Dawes, John T., F.G.S. Cefn Mawr Hall, Mold, North Wales.
1864. ‡DAWKINS, W. BOYD, M.A., F.R.S., F.G.S., F.S.A., Professor of Geology and Palæontology in the Victoria University, Owens College, Manchester. Woodhurst, Fallowfield, Manchester.
Dawson, John. Barley House, Exeter.
1855. ‡DAWSON, JOHN W., M.A., LL.D., F.R.S., F.G.S., Principal of M'Gill College, Montreal, Canada.
1859. *Dawson, Captain William G. Plumstead Common-road, Kent, S.E.
1879. ‡Day, Francis. Kenilworth House, Cheltenham.
1871. ‡DAY, ST. JOHN VINCENT, C.E., F.R.S.E. 166 Buchanan-street, Glasgow.
1870. §DEACON, G. F., M.I.C.E. Rock Ferry, Liverpool.
1861. ‡Deacon, Henry. Appleton House, near Warrington.
1861. ‡Dean, Henry. Colne, Lancashire.
1870. *Deane, Rev. George, B.A., D.Sc., F.G.S. Spring Hill College, Moseley, near Birmingham.
1866. ‡DEBUS, HEINRICH, Ph.D., F.R.S., F.C.S., Lecturer on Chemistry at Guy's Hospital, London, S.E.
1882. *DE CHAUMONT, FRANÇOIS, M.D., F.R.S., Professor of Hygiène in the Royal Victoria Hospital, Netley.
1878. ‡Delany, Rev. William. St. Stanislaus College, Tullamore.
1854. *DE LA RUE, WARREN, M.A., D.C.L., Ph.D., F.R.S., F.C.S., F.R.A.S. 73 Portland-place, London, W.
1879. ‡De la Sala, Colonel. Sevilla House, Navarino-road, London, N.W.
1870. ‡De Meschin, Thomas, M.A., LL.D. 4 Hare-court, Temple, London, E.C.
Denchar, John. Morningside, Edinburgh.

Year of Election.

1875. ‡Denny, William. Seven Ship-yard, Dumbarton.
Dent, William Yerbury. Royal Arsenal, Woolwich.
1870. *Denton, J. Bailey. 22 Whitehall-place, London, S.W.
1874. §De Rance, Charles E., F.G.S. 28 Jermyn-street, London, S.W.
1856. *Derby, The Right Hon. the Earl of, M.A., LL.D., F.R.S., F.R.G.S. 23 St. James's-square, London, S.W.; and Knowsley, near Liverpool.
1874. *Derham, Walter, M.A., LL.M., F.G.S. Henleaze Park, Westbury-on-Trym, Bristol.
1878. ‡De Rinzy, James Harward. Khelat Survey, Sukkur, India.
1868. ‡Dessé, Etheldred, M.B., F.R.C.S. 43 Kensington Gardens-square, Bayswater, London, W.
De Tabley, George, Lord, F.Z.S. Tabley House, Knutsford, Cheshire.
1869. ‡Devon, The Right Hon. the Earl of, D.C.L. Powderham Castle, near Exeter.
*Devonshire, His Grace the Duke of, K.G., M.A., LL.D., F.R.S., F.G.S., F.R.G.S., Chancellor of the University of Cambridge. Devonshire House, Piccadilly, London, W.; and Chatsworth, Derbyshire.
1868. ‡Dewar, James, M.A., F.R.S., F.R.S.E., Fullerian Professor of Chemistry in the Royal Institution, London, and Jacksonian Professor of Natural Experimental Philosophy in the University of Cambridge. 19 Brookside, Cambridge.
1881. ‡Dewar, Mrs. 19 Brookside, Cambridge.
1872. ‡Dewick, Rev. E. S., M.A., F.G.S. 2 Southwick-place, Hyde Park, London, W.
1873. *Dew-Smith, A. G. 7A Eaton-square, London, S.W.
1864. *Dickinson, F. H., F.G.S. Kingweston, Somerton, Taunton; and 121 St. George's-square, London, S.W.
1863. ‡Dickinson, G. T. Claremont-place, Newcastle-on-Tyne.
1867. ‡Dickson, Alexander, M.D., Professor of Botany in the University of Edinburgh. 11 Royal-circus, Edinburgh.
1881. §Dickson, Edmund. West Cliff, Preston.
1862. *Dilke, Sir Charles Wentworth, Bart., M.P., F.R.G.S. 76 Sloane-street, London, S.W.
1877. §Dillon, James, C.E. Stratford House, Silchester-road, Glengeary, Co. Dublin.
1848. ‡Dillwyn, Lewis Llewelyn, M.P., F.L.S., F.G.S. Parkwerne, near Swansea.
1872. §Dines, George. Woodside, Hersham, Walton-on-Thames.
1869. ‡Dingle, Edward. 19 King-street, Tavistock.
1859. *Dingle, Rev. J. Lanchester Vicarage, Durham.
1876. ‡Ditchfield, Arthur. 12 Taviton-street, Gordon-square, London, W.C.
1868. ‡Dittmar, William, F.R.S., F.C.S., F.R.S.E., Professor of Chemistry in Anderson's College, Glasgow.
1874. *Dixon, A. E. Dunowen, Cliftonville, Belfast.
1853. ‡Dixon, Edward, M.I.C.E. Wilton House, Southampton.
1879. *Dixon, Harold B., M.A., F.C.S. Trinity College, Oxford.
*Dobbin, Leonard, M.R.I.A. 27 Gardiner's-place, Dublin.
1851. ‡Dobbin, Orlando T., LL.D., M.R.I.A. Ballivor, Kells, Co. Meath.
1860. *Dobbs, Archibald Edward, M.A. 34 Westbourne Park, London, W.
1878. *Dobson, G. E., M.A., M.B., F.L.S. Royal Victoria Hospital, Netley, Southampton.

Year of Election.

1864. *Dobson, William. Oakwood, Bathwick Hill, Bath.
1875. *Docwra, George, jun. Grosvenor-road, Handsworth, Birmingham.
1870. *Dodd, John. 53 Cable-street, Liverpool.
1876. ‡Dodds, J. M. 15 Sandyford-place, Glasgow.
Dolphin, John. Delves House, Berry Edge, near Gateshead.
1851. ‡Domvile, William C., F.Z.S. Thorn Hill, Bray, Dublin.
1867. ‡Don, John. The Lodge, Broughty Ferry, by Dundee.
1867. ‡Don, William G. St. Margaret's, Broughty Ferry, by Dundee.
1882. §Donaldson, John. Tower House, Chiswick, Middlesex.
1873. ‡Donham, Thomas. Huddersfield.
1869. ‡Donisthorpe, G. T. St. David's Hill, Exeter.
1877. *Donkin, Bryan, jun. May's Hill, Shortlands, Kent.
1874. ‡Donnell, Professor, M.A. 76 Stephen's-green South, Dublin.
1861. ‡Donnelly, Colonel, R.E. South Kensington Museum, London, W.
1881. §Dorrington, John Edward. Lypiatt Park, Stroud.
1867. ‡Dougall, Andrew Maitland, R.N. Scotscraig, Tayport, Fifeshire.
1871. ‡Dougall, John, M.D. 2 Cecil-place, Paisley-road, Glasgow.
1863. *Doughty, Charles Montagu. Theberton Hall, Saxmundham, Suffolk.
1876. *Douglas, Rev. G. C. M. 18 Royal-crescent West, Glasgow.
1877. *Douglass, Sir James N., C.E. Trinity House, London, E.C.
1878. ‡Douglass, William. 104 Baggot-street, Dublin.
1870. ‡Dowie, J. Muir. Achanacreagh, Morvern, N.B.
1876. ‡Dowie, Mrs. Muir. Achanacreagh, Morvern, N.B.
1878. ‡Dowling, Thomas. Claireville House, Terenure, Dublin.
1883. §Downes, Rev. W. Kentisbeare, Collumpton, Devon.
1857. ‡Downing, S., C.E., LL.D., Professor of Civil Engineering in the University of Dublin. 4 The Hill, Monkstown, Co. Dublin.
1878. ‡Dowse, The Right Hon. Baron. 38 Mountjoy-square, Dublin.
1865. *Dowson, E. Theodore, F.M.S. Geldeston, near Beccles, Suffolk.
1881. §Dowson, Joseph Emerson, C.E. 3 Great Queen-street, London, S.W.
1882. §Dowson, Rev. W. Kentisbeare, Collumpton, Devon.
1868. ‡Dresser, Henry E., F.Z.S. 6 Tenterden-street, Hanover-square, London, W.
1873. §Drew, Frederic, F.G.S., F.R.G.S. Eton College, Windsor.
1869. §Drew, Joseph, LL.D., F.R.A.S., F.G.S. Weymouth.
1879. ‡Drew, Joseph, M.B. Foxgrove-road, Beckenham, Kent.
1865. ‡*Drew, Robert A. 6 Stanley-place, Duke-street, Broughton, Manchester.*
1879. ‡Drew, Samuel, M.D., D.Sc., F.R.S.E. Chapelton, near Sheffield.
1872. *Druce, Frederick. 27 Oriental-place, Brighton.
1874. ‡*Druitt, Charles. Hampden-terrace, Rugby-road, Belfast.*
1870. §Drysdale, J. J., M.D. 36A Rodney-street, Liverpool.
1856. *Ducie, The Right. Hon. Henry John Reynolds Moreton, Earl of, F.R.S., F.G.S. 16 Portman-square, London, W.; and Tortworth Court, Wotton-under-Edge.
1870. ‡Duckworth, Henry, F.L.S., F.G.S. Holme House, Columbia-road, Oxton, Birkenhead.
1867. *Duff, The Right Hon. Mountstuart Elphinstone Grant-, F.R.S., F.R.G.S., Governor of Madras. Care of W. Hunter, Esq., 14 Adelphi-court, Union-street, Aberdeen.
1852. ‡Dufferin and Clandeboye, The Right Hon. the Earl of, K.P., K.C.B., LL.D., F.R.S., F.R.G.S. Clandeboye, near Belfast, Ireland.
1877. ‡Duffey, George F., M.D. 30 Fitzwilliam-place, Dublin.
1875. ‡Duffin, W. E. L'Estrange, C.E. Waterford.
1859. *Duncan, Alexander. 7 Prince's-gate, London, S.W.
1859. ‡*Duncan Charles. 52 Union-place, Aberdeen*
1866. *Duncan, James. 71 Cromwell-road, South Kensington, London, W.
Duncan, J. F., M.D. 8 Upper Merrion-street, Dublin.

Year of Election.

1871. ‡Duncan, James Matthew, M.D. 30 Charlotte-square, Edinburgh.
1867. §DUNCAN, PETER MARTIN, M.B., F.R.S., F.G.S., Professor of Geology in King's College, London. 4 St. George's-terrace, Regent's Park-road, London, N.W.
1880. §Duncan, William S. 79 Wolverhampton-road, Stafford.
1881. §Duncombe, The Hon. Cecil. Nawton Grange, York.
1881. ‡Dunhill, Charles H. Gray's-court, York.
1853. *Dunlop, William Henry. Annanhill, Kilmarnock, Ayrshire.
1865. ‡Dunn, David. Annet House, Skelmorlie, by Greenock, N.B.
1876. *Dunn, James. 64 Robertson-street, Glasgow.
1882. §Dunn, J. T. College of Physical Science, Newcastle-on-Tyne.
1876. ‡Dunnachie, James. 2 West Regent-street, Glasgow.
1878. ‡Dunne, D. B., M.A., Ph.D., Professor of Logic in the Catholic University of Ireland. 4 Clanwilliam-place, Dublin.
1859. ‡Duns, Rev. John, D.D., F.R.S.E. New College, Edinburgh.
1866. ‡Duprey, Perry. Woodbury Down, Stoke Newington, London, N.
1869. ‡D'Urban, W. S. M., F.L.S. 4 Queen-terrace, Mount Radford, Exeter.
1860. ‡DURHAM, ARTHUR EDWARD, F.R.C.S., F.L.S., Demonstrator of Anatomy, Guy's Hospital. 82 Brook-street, Grosvenor-square, London, W.
Dykes, Robert. Kilmorie, Torquay, Devon.
1869. *Dymond, Edward E. Oaklands, Aspley Guise, Woburn.

1868. ‡Eade, Peter, M.D. Upper St. Giles's-street, Norwich.
1861. ‡Eadson, Richard. 13 Hyde-road, Manchester.
1877. ‡Earle, Ven. Archdeacon, M.A. West Alvington, Devon.
*EARNSHAW, Rev. SAMUEL, M.A. 14 Broomfield, Sheffield.
1874. §Eason, Charles. 30 Kenilworth-square, Rathgar, Dublin.
1871. *EASTON, EDWARD, C.E., F.G.S. 11 Delahay-street, Westminster, S.W.
1863. §Easton, James. Nest House, near Gateshead, Durham.
1876. ‡Easton, John, C.E. Durie House, Abercromby-street, Helensburgh, N.B.
1870. §Eaton, Richard. 27 Friargate, Derby.
Ebden, Rev. James Collett, M.A., F.R.A.S. Great Stukeley Vicarage, Huntingdonshire.
1861. ‡Ecroyd, William Farrer. Spring Cottage, near Burnley.
1858. *Eddison, Francis. Syward Lodge, Dorchester.
1870. *Eddison, John Edwin, M.D., M.R.C.S. 29 Park-square, Leeds.
*Eddy, James Ray, F.G.S. Carleton Grange, Skipton.
Eden, Thomas. Talbot-road, Oxton.
1859. ‡Edmond, James. Cardens Haugh, Aberdeen.
1870. *Edmonds, F. B. 72 Portsdown-road, London, W.
1867. *Edward, Allan. Farington Hall, Dundee.
1867. ‡Edward, Charles. Chambers, 8 Bank-street, Dundee.
1855. *EDWARDS, Professor J. BAKER, Ph.D., D.C.L. Montreal, Canada.
1859. *Eisdale, David A., M.A. 38 Dublin-street, Edinburgh.
1873. ‡*Elcock, Charles. 30 Lyme-street, Shakspere-street, Ardwick, Manchester.*
1876. ‡Elder, Mrs. 6 Claremont-terrace, Glasgow.
1868. ‡Elger, Thomas Gwyn Empy, F.R.A.S. St. Mary, Bedford.
Ellacombe, Rev. H. T., F.S.A. Clyst St. George, Topsham, Devon.
1863. ‡Ellenberger, J. L. Worksop.
1880. *Elliot, Colonel Charles, C.B. Hazelbank, Murrayfield, Midlothian, N.B.
1855. §Elliot, Robert, F.B.S.E. Wolfelee, Hawick, N.B.

Year of Election.

1861. *ELLIOT, Sir WALTER, K.C.S.I., F.R.S., F.L.S. Wolfelee, Hawick, N.B.
1864. ‡Elliott, E. B. Washington, United States.
1872. ‡Elliott, Rev. E. B. 11 Sussex-square, Kemp Town, Brighton.
Elliott, John Fogg. Elvet Hill, Durham.
1879. §Elliott, Joseph W. Post Office, Bury, Lancashire.
1864. *ELLIS, ALEXANDER JOHN, B.A., F.R.S., F.S.A. 25 Argyll-road, Kensington, London, W.
1877. ‡Ellis, Arthur Devonshire. School of Mines, Jermyn-street, London, S.W.; and Thurnscoe Hall, Rotherham, Yorkshire.
1875. *Ellis, H. D. 67 Ladbroke Grove-road, Notting Hill, London, W.
1864. *Ellis, Joseph. Hampton Lodge, Brighton.
1880. §ELLIS, J. H. Town Hall, Southport.
1864. ‡Ellis, J. Walter. High House, Thornwaite, Ripley, Yorkshire.
*Ellis, Rev. Robert, A.M. The Institute, St. Saviour's Gate, York.
1869. ‡ELLIS, WILLIAM HORTON. Hartwell House, Exeter.
Ellman, Rev. E. B. Berwick Rectory, near Lewes, Sussex.
1862. ‡Elphinstone, H. W., M.A., F.L.S. Cadogan-place, London, S.W.
1863. ‡Embleton, Dennis, M.D. Northumberland-street, Newcastle-on-Tyne.
1863. ‡Emery, The Ven. Archdeacon, B.D. Ely, Cambridgeshire.
1858. ‡Empson, Christopher. Bramhope Hall, Leeds.
1866. ‡Enfield, Richard. Low Pavement, Nottingham.
1866. ‡Enfield, William. Low Pavement, Nottingham.
1853. ‡English, Edgar Wilkins. Yorkshire Banking Company, Lowgate, Hull.
1869. ‡English, J. T. Stratton, Cornwall.
ENNISKILLEN, The Right Hon. WILLIAM WILLOUGHBY, Earl of, LL.D., D.C.L., F.R.S., F.G.S., M.R.I.A. 65 Eaton-place, London, S.W.; and Florence Court, Fermanagh, Ireland.
1869. *Enys, John Davis. Care of F. G. Enys, Esq., Enys, Penryn, Cornwall.
1844. ‡Erichsen, John Eric, F.R.S., F.R.C.S., Professor of Clinical Surgery in University College, London. 6 Cavendish-place, London, W.
1864. *Eskrigge, R. A., F.G.S. 18 Hackins-hey, Liverpool.
1862. *ESSON, WILLIAM, M.A., F.R.S., F.C.S., F.R.A.S. Merton College; and 1 Bradmore-road, Oxford.
1878. ‡Estcourt, Charles, F.C.S. 8 St. James's-square, John Dalton-street, Manchester.
Estcourt, Rev. W. J. B. Long Newton, Tetbury.
1869. ‡ETHERIDGE, ROBERT, F.R.S.L. & E., F.G.S., Assistant Keeper (Geological and Palæontological Department) Natural History Museum (British Museum). 19 Halsey-street, Cadogan-place, London, S.W.
1881. ‡Evans, Alfred. Exeter College, Oxford.
1870. *Evans, Arthur John, F.S.A. Nash Mills, Hemel Hempsted.
1865. *EVANS, Rev. CHARLES, M.A. The Rectory, Solihull, Birmingham.
1876. ‡EVANS, Captain Sir FREDERICK J. O., K.C.B., R.N., F.R.S., F.R.A.S., F.R.G.S., Hydrographer to the Admiralty. 116 Victoria-street, Westminster, S.W.
1869. *Evans, H. Saville W. Wimbledon Park House, Wimbledon, Surrey.
1861. *EVANS, JOHN, D.C.L., LL.D., V.P.R.S., F.S.A., F.G.S. 65 Old Bailey, London, E.C.; and Nash Mills, Hemel Hempsted.
1881. §Evans, Lewis. Picton Villa, Carmarthen.
1876. ‡Evans, Mortimer, C.E. 97 West Regent-street, Glasgow.

Year of Election.

1865. ‡EVANS, SEBASTIAN, M.A., LL.D. Heathfield, Alleyn Park, Lower Norwood, S.E.
1875. ‡Evans, Sparke. 3 Apsley-road, Clifton, Bristol.
1866. ‡Evans, Thomas, F.G.S. Belper, Derbyshire.
1865. *Evans, William. The Spring, Kenilworth.
1871. §Eve, H. Weston, M.A. University College, London, W.C.
1868. *EVERETT, J. D., M.A., D.C.L., F.R.S. L. & E., Professor of Natural Philosophy in Queen's College, Belfast. Lennox-vale, Belfast.
1880. ‡Everingham, Edward. St. Helen's-road, Swansea.
1863. *Everitt, George Allen, F.R.G.S. Knowle Hall, Warwickshire.
1881. ‡Ewart, J. Cossar, M.D., Professor of Natural History in the University of Edinburgh.
1874. ‡Ewart, William, M.P. Glenmachan, Belfast.
1874. ‡Ewart, W. Quartus. Glenmachan, Belfast.
1859. *Ewing, Archibald Orr, M.P. Ballikinrain Castle, Killearn, Stirlingshire.
1876. *Ewing, James Alfred, B.Sc., F.R.S.E., Professor of Mechanical Engineering in the University of Tokio, Japan. 12 Laurel Bank, Dundee.
1871. *Exley, John T., M.A. 1 Cotham-road, Bristol.
1846. *Eyre, George Edward, F.G.S., F.R.G.S. 59 Lowndes-square, London, S.W.; and Warrens, near Lyndhurst, Hants.
1882. §Eyre, G. E. Briscoe. Warrens, near Lyndhurst, Hants.
1866. ‡EYRE, Major-General Sir VINCENT, K.C.S.I. Athenæum Club, Pall Mall, London, S.W.
Eyton, Charles. Hendred House, Abingdon.

1865. ‡FAIRLEY, THOMAS, F.R.S.E., F.C.S. 8 Newton-grove, Leeds.
1876. ‡Fairlie, James M. Charing Cross Corner, Glasgow.
1870. ‡Fairlie, Robert, C.E. Woodlands, Clapham Common, London, S.W.
1878. *Fairlie, Robert F. Palace-chambers, Victoria-street, Westminster, S.W.
1864. ‡Falkner, F. H. Lyncombe, Bath.
1877. §Faraday, F. J., F.L.S, F.S.S. College Chambers, 17 Brazenose-street, Manchester.
1879. *Farnworth, Ernest. Swindon, near Dudley.
1859. ‡Farquharson, Robert O. Houghton, Aberdeen.
1861. ‡FARR, WILLIAM, C.B., M.D., D.C.L. 78 Portsdown-road, Maida Hill, London, W.
1866. *FARRAR, Rev. FREDERICK WILLIAM, M.A., D.D., F.R.S., Canon of Westminster. St. Margaret's Rectory, Westminster, S.W.
1857. ‡Farrelly, Rev. Thomas. Royal College, Maynooth.
1869. *Faulding, Joseph. The Grange, Greenhill Park, New Barnet, Herts.
1859. *FAWCETT, The Right Hon. HENRY, M.A., M.P., F.R.S., Professor of Political Economy in the University of Cambridge. 51 The Lawn, South Lambeth-road, London, S.W.; and 18 Brookside, Cambridge.
1863. ‡Fawcus, George. Alma-place, North Shields.
1873. *Fazakerley, Miss. The Castle, Denbigh.
1845. ‡Felkin, William, F.L.S. The Park, Nottingham.
Fell, John B. Spark's Bridge, Ulverstone, Lancashire.
1864. *FELLOWS, FRANK P., F.S.A., F.S.S. 8 The Green, Hampstead, London, N.W.
1852. ‡Fenton, S. Greame. 9 College-square; and Keswick, near Belfast.
1876. *Fergus, Andrew, M.D. 3 Elmbank-crescent, Glasgow.

Year of Election.

1876. ‡Ferguson, Alexander A. 11 Grosvenor-terrace, Glasgow.
1859. ‡Ferguson, John. Cove, Nigg, Inverness.
1871. *Ferguson, John, M.A., Professor of Chemistry in the University of Glasgow.
1867. ‡Ferguson, Robert M., Ph.D., F.R.S.E. 8 Queen-street, Edinburgh.
1857. ‡Ferguson, Sir Samuel, LL.D., Q.C. 20 Great George's-street North, Dublin.
1854. ‡Ferguson, William, F.L.S., F.G.S. Kinmundy, near Mintlaw, Aberdeenshire.
1867. *Fergusson, H. B. 13 Airlie-place, Dundee.
1863. *FERNIE, JOHN. Bonchurch, Isle of Wight.
1862. ‡FERRERS, Rev. NORMAN MACLEOD, D.D., F.R.S. Caius College Lodge, Cambridge.
1873. ‡Ferrier, David, M.A., M.D., F.R.S., Professor of Forensic Medicine in King's College. 16 Upper Berkeley-street, London, W.
1882. §Fewings, James, B.A., B.Sc. The Grammar School, Southampton.
1875. ‡Fiddes, Walter. Clapton Villa, Tyndall's Park, Clifton, Bristol.
1868. ‡Field, Edward. Norwich.
1869. *FIELD, ROGERS, B.A., C.E. 5 Cannon-row, Westminster, S.W.
1876. ‡*Fielden, James. 2 Darnley-street, Pollokshields, near Glasgow.*
1882. §Filliter, Freeland. St. Martin's House, Wareham, Dorset.
Finch, John. Bridge Work, Chepstow.
Finch, John, jun. Bridge Work, Chepstow.
1878. *Findlater, William, M.P. 2 Fitzwilliam-square, Dublin.
1881. §Firth, Lieut.-Colonel Sir Charles. Heckmondwike.
1868. ‡Firth, G. W. W. St. Giles's-street, Norwich.
Firth, Thomas. Northwick.
1863. *Firth, William. Burley Wood, near Leeds.
1851. *FISCHER, WILLIAM L. F., M.A., LL.D., F.R.S. St. Andrews, Scotland.
1858. ‡Fishbourne, Admiral E. G., R.N. 26 Hogarth-road, Earl's Court-road, London, S.W.
1869. ‡FISHER, Rev. OSMOND, M.A., F.G.S. Harlton Rectory, near Cambridge.
1873. §Fisher, William. Maes Fron, near Welshpool, Montgomeryshire.
1879. ‡Fisher, William. Norton Grange, near Sheffield.
1875. *Fisher, W. W., M.A., F.C.S. 2 Park-crescent, Oxford.
1858. ‡Fishwick, Henry. Carr-hill, Rochdale.
1871. *Fison, Frederick W., F.C.S. Eastmoor, Ilkley, Yorkshire.
1871. ‡FITCH, J. G., M.A. 5 Lancaster-terrace, Regent's Park, London, N.W.
1868. ‡Fitch, Robert, F.G.S., F.S.A. Norwich.
1878. ‡Fitzgerald, C. E., M.D. 27 Upper Merrion-street, Dublin.
1878. §FITZGERALD, GEORGE FRANCIS, M.A. Trinity College, Dublin.
1857. ‡Fitzpatrick, Thomas, M.D. 31 Lower Baggot-street, Dublin.
1881. ‡Fitzsimmons, Henry, M.D. Minster-yard, York.
1865. ‡Fleetwood, D. J. 45 George-street, St. Paul's, Birmingham.
Fleetwood, Sir Peter Hesketh, Bart. Rossall Hall, Fleetwood, Lancashire.
1850. ‡Fleming, Professor Alexander, M.D. 121 Hagley-road, Birmingham.
1881. ‡Fleming, Rev. Canon James, B.D. The Residence, York.
1876. ‡Fleming, James Brown. Beaconsfield, Kelvinside, near Glasgow.
1876. ‡Fleming, Sandford. Ottawa, Canada.
1867. §FLETCHER, ALFRED E. 5 Edge-lane, Liverpool.
1870. ‡Fletcher, B. Edgington. Norwich.
1869. ‡FLETCHER, LAVINGTON E., C.E. 41 Corporation-street, Manchester.
Fletcher, T. B. E., M.D. 7 Waterloo-street, Birmingham.

Year of Election.

1862. ‡FLOWER, WILLIAM HENRY, LL.D., F.R.S., F.L.S., F.G.S., F.R.C.S., Hunterian Professor of Comparative Anatomy, and Conservator of the Museum of the Royal College of Surgeons. Royal College of Surgeons, Lincoln's-Inn-fields, London, W.C.
1877. *Floyer, Ernest A., F.R.G.S., F.L.S. 7 The Terrace, Putney, S.W.
1881. ‡Foljambe, Cecil G. S., M.P. 2 Carlton House-terrace, Pall Mall, London, S.W.
1879. ‡Foote, Charles Newth, M.D. 3 Albion-place, Sunderland.
1879. ‡Foote, Harry D'Oyley, M.D. Rotherham, Yorkshire.
1880. §Foote, R. Bruce. Care of Messrs. H. S. King & Co., 65 Cornhill, London, E.C.
1873. *FORBES, Professor GEORGE, M.A., F.R.S.E. 35 Duke-street, St. James's, London, S.W.
1877. ‡Forbes, W. A., B.A., F.Z.S. West Wickham, Kent.
Ford, H. R. Morecombe Lodge, Yealand Conyers, Lancashire.
1866. ‡Ford, William. Hartsdown Villa, Kensington Park-gardens East, London, W.
1875. *FORDHAM, H. GEORGE, F.G.S. Odsey Grange, Royston, Cambridgeshire.
*Forrest, William Hutton. 1 Pitt-terrace, Stirling.
1867. ‡Forster, Anthony. Finlay House, St. Leonard's-on-Sea.
1858. *FORSTER, The Right Hon. WILLIAM EDWARD, M.P., F.R.S. 80 Eccleston-square, London, S.W.; and Wharfeside, Burley-in-Wharfedale, Leeds.
1854. *Fort, Richard. Read Hall, Whalley, Lancashire.
1877. ‡FORTESCUE, The Right Hon. the Earl. Castle Hill, North Devon.
1882. §Forward, Henry. 3 Burr-street, London, E.
1870. ‡Forwood, William B. Hopeton House, Seaforth, Liverpool
1875. ‡Foster, A. Le Neve. East Hill, Wandsworth, Surrey, S.W.
1865. ‡Foster, Balthazar, M.D., Professor of Medicine in Queen's College, Birmingham. 16 Temple-row, Birmingham.
1865. *FOSTER, CLEMENT LE NEVE, B.A., D.Sc., F.G.S. Llandudno.
1857. *FOSTER, GEORGE CAREY, B.A., F.R.S., F.C.S., Professor of Physics in University College, London. 12 Hilldrop-road, London, N.
1881. ‡Foster, J. L. Ogleforth, York.
1845. ‡Foster, John N. Sandy Place, Sandy, Bedfordshire.
1877. §Foster, Joseph B. 6 James-street, Plymouth.
1859. *FOSTER, MICHAEL, M.A., M.D., Sec. R.S., F.L.S., F.C.S. Trinity College, and Great Shelford, near Cambridge.
1863. ‡Foster, Robert. 30 Rye-hill, Newcastle-upon-Tyne.
1859. **Foster, S. Lloyd. Brundall Lodge, Ealing, Middlesex, W.*
1873. *Foster, William. Harrowins House, Queensbury, Yorkshire.
1870. ‡*Foulger, Edward.* 55 *Kirkdale-road, Liverpool.*
1866. ‡Fowler, George, M.I.C.E., F.G.S. Basford Hall, near Nottingham.
1868. ‡Fowler, G. G. Gunton Hall, Lowestoft, Suffolk.
1876. *Fowler, John. 4 Kelvin Bank-terrace, Glasgow.
1882. §FOWLER, JOHN, M. Inst. C.E., F.G.S. 2 Queen Square-place, Westminster, S.W.
1870. *Fowler, Robert Nicholas, M.A., M.P., F.R.G.S. 50 Cornhill, London, E.C.
1860. *Fox, Rev. Edward, M.A. Upper Heyford, Banbury.
1876. ‡Fox, St. G. Lane. 9 Sussex-place, London, S.W.
*Fox, Joseph Hayland. The Cleve, Wellington, Somerset.
1860. ‡Fox, Joseph John. Church-row, Stoke Newington, London, N.
1881. *FOXWELL, HERBERT S., M.A., Professor of Political Economy in University College, London. St. John's College, Cambridge.

Year of Election.

1866. *Francis, G. B. Inglesby House, Stoke Newington-green, London, N.
FRANCIS, WILLIAM, Ph.D., F.L.S., F.G.S., F.R.A.S. Red Lion-court, Fleet-street, London, E.C.; and Manor House, Richmond, Surrey.
1846. ‡FRANKLAND, EDWARD, D.C.L., Ph.D., F.R.S., F.C.S., Professor of Chemistry in the Royal School of Mines. The Yews, Reigate Hill, Surrey.
*Frankland, Rev. Marmaduke Charles. Chowbent, near Manchester.
1882. §Fraser, Alexander, M.B. Owens College, Manchester.
1859. ‡Fraser, George B. 3 Airlie-place, Dundee.
Fraser, James. 25 Westland-row, Dublin.
Fraser, James William. 8A Kensington Palace-gardens, London, W.
1865. *FRASER, JOHN, M.A., M.D. Chapel Ash, Wolverhampton.
1871. ‡FRASER, THOMAS R., M.D., F.R.S. L. & E. 3 Grosvenor-street, Edinburgh.
1859. *Frazer, Daniel. 113 Buchanan-street, Glasgow.
1871. ‡Frazer, Evan L. R. Brunswick-terrace, Spring Bank, Hull.
1860. ‡Freeborn, Richard Fernandez. 38 Broad-street, Oxford.
1847. *Freeland, Humphrey William, F.G.S. West-street, Chichester.
1877. §Freeman, Francis Ford. Black Friars House, Plymouth.
1865. ‡Freeman, James. 15 Francis-road, Edgbaston, Birmingham.
1880. ‡Freeman, Thomas. Brynhyfryd, Swansea.
1841. Freeth, Major-General S. 30 Royal-crescent, Notting Hill, London, W.
Frere, George Edward, F.R.S. Roydon Hall, Diss, Norfolk.
1869. ‡FRERE, The Right Hon. Sir H. BARTLE E., Bart., G.C.S.I., G.C.B., F.R.S., F.R.G.S. Athenæum Club, London, S.W.
1869. ‡Frere, Rev. William Edward. The Rectory, Bilton, near Bristol.
1857. *Frith, Richard Hastings, C.E., M.R.I.A., F.R.G.S.I. 48 Summerhill, Dublin.
1869. ‡Frodsham, Charles. 26 Upper Bedford-place, Russell-square, London, W.C.
1882. §Frost, Edward P., J.P. West Wratting Hall, Cambridgeshire.
1847. ‡Frost, William. Wentworth Lodge, Upper Tulse Hill, London, S.W.
1875. ‡Fry, F. J. 104 Pembroke-road, Clifton, Bristol.
Fry, Francis. Cotham, Bristol.
1875. *Fry, Joseph Storrs. 2 Charlotte-street, Bristol.
1872. *Fuller, Rev. A. Pallant, Chichester.
1859. ‡FULLER, FREDERICK, M.A. 9 Palace-road, Surbiton.
1869. ‡FULLER, GEORGE, C.E., Professor of Engineering in Queen's College, Belfast. 6 College-gardens, Belfast.
1864. *Furneaux, Rev. Alan. St. German's Parsonage, Cornwall.

1881. §Gabb, Rev. James, M.A. Bulmer Rectory, Welburn, Yorkshire.
*Gadesden, Augustus William, F.S.A. Ewell Castle, Surrey.
1857. ‡GAGES, ALPHONSE, M.R.I.A. Museum of Irish Industry, Dublin.
1863. *Gainsford, W. D. Richmond Hill, Sheffield.
1876. ‡Gairdner, Charles. Broom, Newton Mearns, Renfrewshire.
1850. ‡Gairdner, Professor W. T., M.D. 225 St. Vincent-street, Glasgow.
1861. ‡Galbraith, Andrew. Glasgow.
GALBRAITH, Rev. J. A., M.A., M.R.I.A. Trinity College, Dublin.
1876. ‡Gale, James M. 23 Miller-street, Glasgow.
1863. ‡Gale, Samuel, F.C.S. 338 Oxford-street, London, W.
1861. ‡Galloway, Charles John. Knott Mill Iron Works, Manchester.
1861. ‡Galloway, John, jun. Knott Mill Iron Works, Manchester.
1875. §GALLOWAY, W., H.M. Inspector of Mines. Cardiff.

Year of Election.

1860. *GALTON, Captain DOUGLAS, C.B., D.C.L., F.R.S., F.L.S., F.G.S., F.R.G.S. (GENERAL SECRETARY.) 12 Chester-street, Grosvenor-place, London, S.W.

1860. *GALTON, FRANCIS, M.A., F.R.S., F.G.S., F.R.G.S. 42 Rutland-gate, Knightsbridge, London, S.W.

1869. ‡GALTON, JOHN C., M.A., F.L.S. 40 Great Marlborough-street, London, W.

1870. ‡Gamble, J. C. St. Helen's, Lancashire.

1872. *Gamble, John G., M.A. Capetown. (Care of Messrs. Ollivier and Brown, 37 Sackville-street, Piccadilly, London. W.)

1870. Gamble, Lieut.-Colonel D. St. Helen's, Lancashire.

1877. ‡Gamble, William. St. Helen's, Lancashire.

1868. ‡GAMGEE, ARTHUR, M.D., F.R.S., F.R.S.E., Professor of Physiology in Owens College, Manchester. Fairview, Princes-road, Fallowfield, Manchester.

1882. *Gardner, H. Dent, F.R.G.S. 25 Northbrook-road, Lee, Kent.

1882. §Gardner, John Starkie, F.G.S. Park House, St. John's Wood Park, London, N.W.

1862. ‡GARNER, ROBERT, F.L.S. Stoke-upon-Trent.

1865. ‡Garner, Mrs. Robert. Stoke-upon-Trent.

1882. §Garnett, William. University College, Nottingham.

1873. ‡Garnham, John. 123 Bunhill-row, London, E.C.

1874. *Garstin, John Ribton, M.A., LL.B., M.R.I.A., F.S.A. Bragans-town, Castlebellingham, Ireland.

1882. §Garton, William. Woolston, Southampton.

1870. ‡Gaskell, Holbrook. Woolton Wood, Liverpool.

1870. *Gaskell, Holbrook, jun. Clayton Lodge, Aigburth, Liverpool.

1847. *Gaskell, Samuel. Windham Club, St. James's-square, London, S.W.

1842. Gaskell, Rev. William, M.A. Plymouth-grove, Manchester.

1862. *Gatty, Charles Henry, M.A., F.L.S., F.G.S. Felbridge Park, East Grinstead, Sussex.

1875. ‡Gavey, J. 43 Stacey-road, Routh, Cardiff.

1875. ‡Gaye, Henry S. Newton Abbot, Devon.

1871. ‡Geddes, John. 9 Melville-crescent, Edinburgh.

1859. ‡Geddes, William D., M.A., Professor of Greek in King's College, Old Aberdeen.

1854. ‡Gee, Robert, M.D. 5 Abercromby-square, Liverpool.

1867. ‡GEIKIE, ARCHIBALD, LL.D., F.R.S. L. & E., F.G.S., Director-General of the Geological Survey of the United Kingdom. Geological Survey Office, Jermyn-street, London, S.W.

1871. ‡Geikie, James, LL.D., F.R.S. L. & E., F.G.S., Murchison Professor of Geology and Mineralogy in the University of Edinburgh. 10 Bright's-crescent, Mayfield, Edinburgh.

1882. §Genese, R. W., M.A., Professor of Mathematics in University College, Aberystwith.

1875. *George, Rev. Hereford B., M.A., F.R.G.S. New College, Oxford.

1870. ‡Gerstl, R., F.C.S. University College, London, W.C.

1870. *Gervis, Walter S., M.D., F.G.S. Ashburton, Devonshire.

1865. ‡Gibbins, William. Battery Works, Digbeth, Birmingham.

1874. ‡Gibson, The Right Hon. Edward, Q.C., M.P. 23 Fitzwilliam-square, Dublin.

1876. *Gibson, George Alexander, M.D., D.Sc., F.R.S.E., F.G.S. 1 Randolph Cliff, Edinburgh.

*Gibson, George Stacey. Saffron Walden, Essex.

1870. ‡Gibson, Thomas. 51 Oxford-street, Liverpool.

1870. ‡Gibson, Thomas, jun. 10 Parkfield-road, Prince's Park, Liverpool.

1842. GILBERT, JOSEPH HENRY, Ph.D., F.R.S., F.C.S. Harpenden, near St. Albans.

Year of Election.

1857. ‡Gilbert, J. T., M.R.I.A. Villa Nova, Blackrock, Dublin.
1859. *Gilchrist, James, M.D. Crichton House, Dumfries.
Gilderdale, Rev. John, M.A. Walthamstow, Essex.
1882. §Giles, Alfred, M.I.C.E. Cosford, Godalming.
1878. §Giles, Oliver. 16 Bellevue-crescent, Clifton, Bristol.
Giles, Rev. William. Netherleigh House, near Chester.
1878. ‡Gill, Rev. A. W. H. 44 Eaton-square, London, S.W.
1871. *Gill, David. The Observatory, Cape Town.
1881. §Gill, H. C. Bootham, York.
1868. ‡Gill, Joseph. Palermo, Sicily. (Care of W. H. Gill, Esq., General Post Office, St. Martin's-le-Grand, E.C.)
1864. ‡Gill, Thomas. 4 Sydney-place, Bath.
1861. *Gilroy, George. Woodlands, Parbold, near Wigan.
1867. ‡Gilroy, Robert. Craigie, by Dundee.
1876. ‡Gimingham, Charles H., F.C.S. 45 St. Augustine's-road, Camden-square, London, N.W.
1867. §Ginsburg, Rev. C. D., D.C.L., LL.D. Holmlea, Virginia Water Station, Chertsey.
1869. ‡Girdlestone, Rev. Canon E., M.A. Olveston, Almondbury, Gloucestershire.
1874. *Girdwood, James Kennedy. Old Park, Belfast.
1850. *Gladstone, George, F.C.S., F.R.G.S. 31 Ventnor-villas, Cliftonville, Brighton.
1849. *Gladstone, John Hall, Ph.D., F.R.S., F.C.S. 17 Pembridge-square, Hyde Park, London, W.
1875. *Glaisher, Ernest Henry. 1 Dartmouth-place, Blackheath, London, S.E.
1861. *Glaisher, James, F.R.S., F.R.A.S. 1 Dartmouth-place, Blackheath, London, S.E.
1871. *Glaisher, J. W. L., M.A., F.R.S., F.R.A.S. Trinity College, Cambridge.
1881. *Glazebrook, R. T., M.A., F.R.S. Trinity College, Cambridge.
1881. §Gleadow, Frederic. 13 Park-square, Leeds.
1870. §Glen, David Corse, F.G.S. 14 Annfield-place, Glasgow.
1859. ‡*Glennie, J. S. Stuart. 6 Stone-buildings, Lincoln's Inn, London, W.C.*
1867. ‡Gloag, John A. L. 10 Inverleith-place, Edinburgh.
Glover, George. Ranelagh-road, Pimlico, London, S.W.
1874. ‡Glover, George T. 30 Donegall-place. Belfast.
1874. ‡*Glover, Thomas. 77 Claverton-street, London, S.W.*
1870. ‡Glynn, Thomas R. 1 Rodney-street, Liverpool.
1872. ‡Goddard, Richard. 16 Booth-street, Bradford, Yorkshire.
1878. *Godlee, J. Lister. 3 New-square, Lincoln's Inn, London, W.C.
1880. §Godman, F. Du Cane, F.R.S., F.L.S. 10 Chandos-street, Cavendish-square, London, W.
1852. ‡Godwin, John. Wood House, Rostrevor, Belfast.
1879. ‡Godwin-Austen, Lieut.-Colonel H. H., F.R.S., F.Z.S. Deepdale, Reigate.
1846. ‡Godwin-Austen, Robert A. C., B.A., F.R.S., F.G.S. Shalford House, Guildford.
1876. ‡Goff, Bruce, M.D. Bothwell, Lanarkshire.
1877. ‡Goff, James. 11 Northumberland-road, Dublin.
1881. §Goldschmidt, Edward. Nottingham.
1873. ‡Goldthorp, Miss R. F. C. Cleckheaton, Bradford, Yorkshire.
1878. ‡Good, Rev. Thomas, B.D. 51 Wellington-road, Dublin.
1852. ‡Goodbody, Jonathan. Clare, King's County, Ireland.
1870. ‡*Goodison, George William, C.E. Gateacre, Liverpool.*
1842. *Goodman, John, M.D. 8 Leicester-street, Southport.

Year of Election.

1865. ‡Goodman, J. D. Minories, Birmingham.
1869. ‡Goodman, Neville. Peterhouse, Cambridge.
1870. *Goodwin, Rev. Henry Albert, M.A., F.R.A.S. Lambourne Rectory, Romford.
1871. *Gordon, Joseph Gordon, F.C.S. 20 King-street, St. James's, London, S.W.
1857. ‡Gordon, Samuel, M.D. 11 Hume-street, Dublin.
1865. ‡Gore, George, LL.D., F.R.S. 50 Islington-row, Edgbaston, Birmingham.
1870. ‡Gossage, William. Winwood, Woolton, Liverpool.
1875. *Gotch, Francis. Stokes Croft, Bristol.
*Gotch, Rev. Frederick William, LL.D. Stokes Croft, Bristol.
*Gotch, Thomas Henry. Kettering.
1873. §Gott, Charles, M.I.C.E. Parkfield-road, Manningham, Bradford, Yorkshire.
1849. ‡Gough, The Hon. Frederick. Perry Hall, Birmingham.
1857. ‡Gough, The Right Hon. George S., Viscount, M.A., F.L.S., F.G.S. St. Helen's, Booterstown, Dublin.
1881. ‡Gough, Thomas, B.Sc., F.C.S. Elmfield College, York.
1868. ‡Gould, Rev. George. Unthank-road, Norwich.
1873. ‡Gourlay, J. McMillan. 21 St. Andrew's-place, Bradford, Yorkshire.
1867. ‡Gourley, Henry (Engineer). Dundee.
1876. ‡Gow, Robert. Cairndowan, Dowanhill, Glasgow.
Gowland, James. London-wall, London, E.C.
1873. §Goyder, Dr. D. Marley House, 88 Great Horton-road, Bradford, Yorkshire.
1861. ‡Grafton, Frederick W. Park-road, Whalley Range, Manchester.
1867. *Graham, Cyril, F.L.S., F.R.G.S. Colonial Office, London, S.W.
1875. ‡Grahame, James. Auldhouse, Pollokshaws, near Glasgow.
1852. *Grainger, Rev. Canon John, D.D., M.R.I.A. Skerry and Rathcavan Rectory, Broughshane, near Ballymena, Co. Antrim.
1871. ‡Grant, Sir Alexander, Bart., M.A., Principal of the University of Edinburgh. 21 Lansdowne-crescent, Edinburgh.
1859. ‡*Grant, Hon. James. Cluny Cottage, Forres.*
1870. ‡Grant, Colonel James A., C.B., C.S.I., F.R.S., F.L.S., F.R.G.S. 19 Upper Grosvenor-street, London, W.
1855. *Grant, Robert, M.A., LL.D., F.R.S., F.R.A.S., Regius Professor of Astronomy in the University of Glasgow. The Observatory, Glasgow.
1854. ‡Grantham, Richard B., C.E., F.G.S. 22 Whitehall-place, London, S.W.
1864. ‡Grantham, Richard F. 22 Whitehall-place, London. S.W.
1881. §Graves, E. 126 King Henry's-road, London, N.W.
1874. ‡Graves, Rev. James, B.A., M.R.I.A. Inisnag Glebe, Stonyford, Co. Kilkenny.
1881. ‡Gray, Alan, LL.B. Minster-yard, York.
1864. *Gray, Rev. Charles. The Vicarage, Blyth, Worksop.
1865. ‡Gray, Charles. Swan-bank, Bilston.
1870. ‡Gray, C. B. 5 Rumford-place, Liverpool.
1876. ‡Gray, Dr. Newton-terrace, Glasgow.
1881. ‡Gray, Edwin, LL.B. Minster-yard, York.
1864. ‡Gray, Jonathan. Summerhill House, Bath.
1859. ‡Gray, Rev. J. H. Bolsover Castle, Derbyshire.
1870. ‡Gray, J. Macfarlane. 127 Queen's-road, Peckham, London, S.E.
1878. ‡Gray, Matthew Hamilton. 14 St. John's Park, Blackheath, London, S.E.

Year of Election.

1878. ‡Gray, Robert Kaye. 14 St. John's Park, Blackheath, London, S.E.
1881. §Gray, Thomas. 21 Haybrom-crescent, Glasgow.
1873. ‡Gray, William, M.R.I.A. 6 Mount Charles, Belfast.
*GRAY, Colonel WILLIAM. Farley Hall, near Reading.
1854. *Grazebrook, Henry. Clent Grove, near Stourbridge, Worcestershire.
1866. §Greaves, Charles Augustus, M.B., LL.B. 101 Friar-gate, Derby.
1869. ‡Greaves, William. Station-street, Nottingham.
1872. ‡Greaves, William. 3 South-square, Gray's Inn, London, W.C.
1872. *Grece, Clair J., LL.D. Redhill, Surrey.
1879. ‡Green, A. F. 15 Ashwood-villas, Headingley, Leeds.
1858. *Greenhalgh, Thomas. Thornydikes, Sharples, near Bolton-le-Moors.
1882. §Greenhill, A. G., M.A., Professor of Mathematics at the Royal Artillery Institution, Woolwich. Emmanuel College, Cambridge.
1881. §Greenhough, Edward. Matlock Bath, Derbyshire.
1863. ‡Greenwell, G. E. Poynton, Cheshire.
1875. ‡Greenwood, Frederick. School of Medicine, Leeds.
1862. *Greenwood, Henry. 32 Castle-street, and the Woodlands, Anfield-road, Anfield, Liverpool.
1877. ‡Greenwood, Holmes. 78 King-street, Accrington.
1849. ‡Greenwood, William. Stones, Todmorden.
1861. *GREG, ROBERT PHILIPS, F.G.S., F.R.A.S. Coles Park, Buntingford, Herts.
1833. Gregg, T. H. 22 Ironmonger-lane, Cheapside, London, E.C.
1860. ‡GREGOR, Rev. WALTER, M.A. Pitsligo, Rosehearty, Aberdeenshire.
1868. ‡Gregory, Charles Hutton, C.E. 1 Delahay-street, Westminster, S.W.
1861. §Gregson, Samuel Leigh. Aigburth-road, Liverpool.
1881. §Gregson, William. Baldersby, Thirsk.
1875. ‡Grenfell, J. Granville, B.A., F.G.S. 5 Albert-villas, Clifton, Bristol.
1875. ‡Grey, Mrs. Maria G. 18 Cadogan-place, London, S.W.
1871. *Grierson, Samuel, Medical Superintendent of the District Asylum, Melrose, N.B.
1859. ‡GRIERSON, THOMAS BOYLE, M.D. Thornhill, Dumfriesshire.
1875. ‡Grieve, David, F.R.S.E., F.G.S. 2 Victoria-terrace, Portobello, Edinburgh.
1870. ‡*Grieve, John, M.D. 21 Lynedock-street, Glasgow.*
1878. ‡Griffin, Robert, M.A., LL.D. Trinity College, Dublin.
1859. *GRIFFITH, GEORGE, M.A., F.C.S. Harrow.
Griffith, George R. Fitzwilliam-place, Dublin.
1870. §Griffith, Rev. Henry, F.G.S. Barnet, Herts.
1870. ‡*Griffith, N. R. The Coppa, Mold, North Wales.*
1847. ‡Griffith, Thomas. Bradford-street, Birmingham.
GRIFFITHS, Rev. JOHN, M.A. Wadham College, Oxford.
1879. §Griffiths, Thomas, F.C.S., F.S.S. Silverdale, Oxton, Birkenhead.
1875. ‡Grignon, James, H.M. Consul at Riga. Riga.
1870. ‡Grimsdale, T. F., M.D. 29 Rodney-street, Liverpool.
1842. Grimshaw, Samuel, M.A. Errwod, Buxton.
1881. §Gripper, Edward. Nottingham.
1864. ‡GROOM-NAPIER, CHARLES OTTLEY. 18 Elgin-road, St. Peter's Park, London, N.W.
1869. §Grote, Arthur, F.L.S., F.G.S. 42 Ovington-square, London, S.W.
GROVE, The Hon. Sir WILLIAM ROBERT, Knt., M.A., D.C.L., F.R.S. 115 Harley-street, London, W.
1863. *GROVES, THOMAS B., F.C.S. 80 St. Mary-street, Weymouth.
1869. ‡GRUBB, HOWARD, F.R.A.S. 40 Leinster-square, Rathmines, Dublin.

Year of Election.

1867. ‡Guild, John. Bayfield, West Ferry, Dundee.
Guinness, Henry. 17 College-green, Dublin.
1842. Guinness, Richard Seymour. 17 College-green, Dublin.
1856. *GUISE, Lieut.-Colonel Sir WILLIAM VERNON, Bart., F.G.S., F.L.S. Elmore Court, near Gloucester.
1862. ‡Gunn, John, M.A., F.G.S. Irstedd Rectory, Norwich.
1877. ‡Gunn, William, F.G.S. Barnard Castle, Darlington.
1866. ‡GÜNTHER, ALBERT C. L. G., M.A., M.D., Ph.D., F.R.S., Keeper of the Zoological Collections in the British Museum. British Museum, London, W.C.
1880. §Guppy, John J. Ivy-place, High-street, Swansea.
1868. *Gurney, John. Sprouston Hall, Norwich.
1876. ‡Guthrie, Francis. Cape Town, Cape of Good Hope.
1859. ‡GUTHRIE, FREDERICK, B.A., F.R.S. L. & E., Professor of Physics in the Royal School of Mines. Science Schools, South Kensington, London, S.W.
1857. ‡Gwynne, Rev. John. Tullyagnish, Letterkenny, Strabane, Ireland.
1876. ‡Gwyther, R. F. Owens College, Manchester.

1865. ‡Hackney, William. 9 Victoria-chambers, Victoria-street, London, S.W.
1866. *Hadden, Frederick J. South Cliff, Scarborough.
1881. §HADDON, ALFRED CORT, B.A., F.Z.S., Professor of Zoology in the Royal College of Science, Dublin.
1866. ‡*Haddon, Henry. Lenton Field, Nottingham.*
Haden, G. N. Trowbridge, Wiltshire.
1842. Hadfield, George. Victoria-park, Manchester.
1870. ‡Hadivan, Isaac. 3 Huskisson-street, Liverpool.
1848. ‡Hadland, William Jenkins. Banbury, Oxfordshire.
1870. ‡Haigh, George. Waterloo, Liverpool.
*Hailstone, Edward, F.S.A. Walton Hall, Wakefield, Yorkshire.
1879. ‡HAKE, H. WILSON, Ph.D., F.C.S. Queenwood College, Hants.
1869. ‡*Hake, R. C. Grasmere Lodge, Addison-road, Kensington, London, W.*
1875. ‡Hale, Rev. Edward, M.A., F.G.S., F.R.G.S. Eton College, Windsor.
1870. ‡*Halhead, W. B. 7 Parkfield-road, Liverpool.*
HALIFAX, The Right Hon. Viscount, G.C.B., F.R.G.S. 10 Belgrave-square, London, S.W.; and Hickleston Hall, Doncaster.
1872. ‡Hall, Dr. Alfred. 30 Old Steine, Brighton.
1879. *Hall, Ebenezer. Abbeydale Park, near Sheffield.
1881. §Hall, Frederick Thomas, F.R.A.S. Moore-place, Esher, Surrey.
1854. *HALL, HUGH FERGIE, F.G.S. Greenheys, Wallasey, Birkenhead.
1859. ‡Hall, John Frederic. Ellerker House, Richmond, Surrey.
1872. *Hall, Captain Marshall. 13 Old-square, Lincoln's Inn, London, W.C.
*Hall, Thomas B. Australia. (Care of J. P. Hall, Esq., Crane House, Great Yarmouth.)
1866. *HALL, TOWNSHEND M., F.G.S. Pilton, Barnstaple.
1860. ‡Hall, Walter. 11 Pier-road, Erith.
1873. *HALLETT, T. G. P., M.A. Claverton Lodge, Bath.
1868. *HALLETT, WILLIAM HENRY, F.L.S. Buckingham House, Marine Parade, Brighton.
Halsall, Edward. 4 Somerset-street, Kingsdown, Bristol.
1858. *Hambly, Charles Hambly Burbridge, F.G.S. The Leys, Barrow-on-Soar, near Loughborough.
1869. §Hamilton, Rowland. Oriental Club, Hanover-square, London, W.
1851. ‡Hammond, C. C. Lower Brook-street, Ipswich.
1881. *Hammond, Robert. 110 Cannon-street, London, E.C.
1878. ‡Hanagan, Anthony. Luckington, Dalkey.

Year of Election.

1878. §Hance, Edward M., LL.B. 103 Hartington-road, Sefton Park, Liverpool.
1875. ‡Hancock, C. F., M.A. 36 Blandford-square, London, N.W.
1863. ‡Hancock, John. 4 St. Mary's-terrace, Newcastle-on-Tyne.
1850. ‡Hancock, John, J.P. The Manor House, Lurgan, Co. Armagh.
1861. ‡Hancock, Walter. 10 Upper Chadwell-street, Pentonville, London, N.
1857. ‡Hancock, William J. 23 Synnot-place, Dublin.
1847. ‡HANCOCK, W. NEILSON, LL.D., M.R.I.A. 64 Upper Gardiner-street, Dublin.
1876. ‡Hancock, Mrs. W. Neilson. 64 Upper Gardiner-street, Dublin.
1865. ‡Hands, M. Coventry.
1882. §Hankinson, R. C. Bassett, Southampton.
1867. ‡Hannah, Rev. John, D.C.L. The Vicarage, Brighton.
1859. ‡Hannay, John. Montcoffer House, Aberdeen.
1853. ‡Hansell, Thomas T. 2 Charlotte-street, Sculcoates, Hull.
*HARCOURT, A. G. VERNON, M.A., F.R.S., F.C.S. (GENERAL SECRETARY.) Cowley Grange, Oxford.
Harcourt, Egerton V. Vernon, M.A., F.G.S. Whitwell Hall, Yorkshire.
1865. ‡Harding, Charles. Harborne Heath, Birmingham.
1869. ‡Harding, Joseph. Millbrooke House, Exeter.
1877. §Harding, Stephen. Bower Ashton, Clifton, Bristol.
1869. ‡Harding, William D. Islington Lodge, King's Lynn, Norfolk.
1874. ‡Hardman, E. T., F.C.S. 14 Hume-street, Dublin.
1872. ‡Hardwicke, Mrs. 192 Piccadilly, London, W.
1880. §Hardy, John. 118 Embden-street, Manchester.
*HARE, CHARLES JOHN, M.D. Berkeley House, 15 Manchester-square, London, W.
1858. ‡Hargrave, James. Burley, near Leeds.
1881. ‡Hargrove, William Wallace. St. Mary's, Bootham, York.
1876. ‡Harker, Allen. 17 Southgate-street, Gloucester.
1878. *Harkness, H. W. Sacramento, California.
1871. §Harkness, William. Laboratory, Somerset House, London, W.C.
1875. *Harland, Rev. Albert Augustus, M.A., F.G.S., F.L.S., F.S.A. The Vicarage, Harefield, Middlesex.
1877. *Harland, Henry Seaton. Brompton, Wykeham Station, York.
1862. *HARLEY, GEORGE, M.D., F.R.S., F.C.S. 25 Harley-street, London, W.
*Harley, John. Ross Hall, near Shrewsbury.
1862. *HARLEY, Rev. ROBERT, F.R.S., F.R.A.S. 19 Woodberry-grove, Green Lanes, Middlesex, N.
1868. *HARMER, F. W., F.G.S. Oakland House, Cringleford, Norwich.
1881. *Harmer, Sidney F., B.Sc. King's College, Cambridge.
1882. §Harper, G. T. Bryn Hyfrydd, Portswood, Southampton.
1872. ‡Harpley, Rev. William, M.A., F.C.P.S. Clayhanger Rectory, Tiverton.
*Harris, Alfred. Lunefield, Kirkby-Lonsdale, Westmoreland.
1871. ‡HARRIS, GEORGE, F.S.A. Iselipps Manor, Northolt, Southall, Middlesex.
1863. ‡Harris, T. W. Grange, Middlesbrough-on-Tees.
1873. ‡*Harris, W. W. Oak-villas, Bradford, Yorkshire.*
1860. ‡Harrison, Rev. Francis, M.A. Oriel College, Oxford.
1864. ‡Harrison, George. Barnsley, Yorkshire.
1873. ‡Harrison, George, Ph.D., F.L.S., F.C.S. 14 St. James's-row, Sheffield.
1874. ‡Harrison, G. D. B. 3 Beaufort-road, Clifton, Bristol.

Year of Election.

1858. *HARRISON, JAMES PARK, M.A. 22 Connaught-street, Hyde Park, London, W.
1870. ‡HARRISON, REGINALD. 51 Rodney-street, Liverpool.
1853. ‡Harrison, Robert. 36 George-street, Hull.
1863. ‡Harrison, T. E. Engineers' Office, Central Station, Newcastle-on-Tyne.
1854.‡ Harrowby, The Right Hon. the Earl of. 39 Grosvenor-square, London, W.; and Sandon Hall, Lichfield.
1876. *Hart, Thomas. Brooklands, Blackburn.
1881. §Hart, Thomas. 11 Richmond-terrace, Blackburn.
1875. ‡Hart, W. E. Kilderry, near Londonderry.
Hartley, James. Sunderland.
1871. ‡Hartley, Walter Noel, F.C.S., Professor of Chemistry in the Royal College of Science, Dublin.
1854. §HARTNUP, JOHN, F.R.A.S. Liverpool Observatory, Bidston, Birkenhead.
1870. ‡Harvey, Enoch. Riversdale-road, Aigburth, Liverpool.
Harvey, J. R., M.D. St. Patrick's-place, Cork.
1878. ‡Harvey, R. J., M.D. 7 Upper Merrion-street, Dublin.
1862. *Harwood, John, jun. Woodside Mills, Bolton-le-Moors.
1882. §Haslam, George James, M.D. Royal Hospital, Salford, Lancashire.
1875. ‡HASTINGS, G. W., M.P. Barnard's Green House, Malvern.
1857. ‡HAUGHTON, Rev. SAMUEL, M.A., M.D., D.C.L., F.R.S., M.R.I.A., F.G.S., Senior Fellow of Trinity College, Dublin. Dublin.
1874. ‡Hawkins, B. Waterhouse, F.G.S. Century Club, East Fifteenth-street, New York.
1872. *Hawkshaw, Henry Paul. 58 Jermyn-street, St. James's, London, S.W.
*HAWKSHAW, Sir JOHN, C.E., F.R.S., F.G.S., F.R.G.S. Hollycombe, Liphook, Petersfield; and 33 Great George-street, London, S.W.
1864. *HAWKSHAW, JOHN CLARKE, M.A., F.G.S. 50 Harrington-gardens, South Kensington, S.W.; and 33 Great George-street, London, S.W.
1868. §HAWKSLEY, THOMAS, C.E., F.R.S., F.G.S. 30 Great George-street, London, S.W.
1863. ‡Hawthorn, William. The Cottage, Benwell, Newcastle-upon-Tyne.
1859. ‡Hay, Sir Andrew Leith, Bart. Rannes, Aberdeenshire.
1877. ‡Hay, Arthur J. Lerwick, Shetland.
1861. *HAY, Rear-Admiral the Right Hon. Sir JOHN C. D., Bart., C.B., M.P., D.C.L., F.R.S. 108 St. George's-square, London, S.W.
1858. ‡Hay, Samuel. Albion-place, Leeds.
1867. ‡Hay, William. 21 Magdalen-yard-road, Dundee.
1857. ‡Hayden, Thomas, M.D. 30 Harcourt-street, Dublin.
1873. *Hayes, Rev. William A., M.A. Dromore, Co. Down, Ireland.
1869. ‡Hayward, J. High-street, Exeter.
1858. *HAYWARD, ROBERT BALDWIN, M.A., F.R.S. The Park, Harrow.
1879. *Hazlehurst, George S. The Elms, Runcorn.
1851. §HEAD, JEREMIAH, C.E., F.C.S. Middlesbrough, Yorkshire.
1869. ‡Head, R. T. The Briars, Alphington, Exeter.
1869. ‡Head, W. R. Bedford-circus, Exeter.
1863. ‡Heald, Joseph. 22 Leazes-terrace, Newcastle-on-Tyne.
1871. §Healey, George. Matson's, Windermere.
1861. *Heape, Benjamin. Northwood, Prestwich, near Manchester.
1882. *Heape, Walter. New Museums, Cambridge.
1877. ‡Hearder, Henry Pollington. Westwell-street, Plymouth.

Year of Election.

1865. ‡Hearder, William. Rocombe, Torquay.
1877. ‡Hearder, William Keep, F.S.A. 195 Union-street, Plymouth.
1866. ‡Heath, Rev. D. J. Esher, Surrey.
1863. ‡Heath, G. Y., M.D. Westgate-street, Newcastle-on-Tyne.
1861. ‡*Heathfield, W. E., F.C.S., F.R.G.S., F.R.S.E. 20 King-street, St. James's, London, S.W.*
1865. ‡Heaton, Harry. Harborne House, Harborne, near Birmingham.
1833. ‡Heaviside, Rev. Canon J. W. L., M.A. The Close, Norwich.
1855. ‡Hector, James, M.D., F.R.S., F.G.S., F.R.G.S., Geological Survey of New Zealand. Wellington, New Zealand.
1867. ‡Heddle, M. Forster, M.D., F.R.S.E., Professor of Chemistry in the University of St. Andrews, N.B.
1869. ‡Hedgeland, Rev. W. J. 21 Mount Radford, Exeter.
1882. §Hedger, Philip. Cumberland-place, Southampton.
1863. ‡Hedley, Thomas. Cox Lodge, near Newcastle-on-Tyne.
1857. *Hemans, George William, C.E., M.R.I.A., F.G.S. 1 Westminster-chambers, Victoria-street, London, S.W.
1867. ‡Henderson, Alexander. Dundee.
1845. ‡*Henderson, Andrew. 120 Gloucester-place, Portman-square, London, W.*
1873. *Henderson, A. L. 49 King William-street, London, E.C.
1874. ‡Henderson, James Alexander. Norwood Tower, Belfast.
1876. *Henderson, William. Williamfield, Irvine, N.B.
1880. *Henderson, Commander W. H., R.N. H.M.S. *Nelson*, Australia.
1856. ‡Hennessy, Henry G., F.R.S., M.R.I.A., Professor of Applied Mathematics and Mechanics in the Royal College of Science for Ireland. 3 Idrone-terrace, Blackrock, Co. Dublin.
1857. ‡Hennessy, Sir John Pope, K.C.M.G., Governor and Commander-in-Chief of Hong Kong.
1873. *Henrici, Olaus M. F. E., Ph.D., F.R.S., Professor of Applied Mathematics in University College, London. Meldorf Cottage, Kemplay-road, Hampstead, London, N.W.
Henry, Franklin. Portland-street, Manchester.
Henry, J. Snowdon. East Dene, Bonchurch, Isle of Wight.
Henry, Mitchell, M.P. Stratheden House, Hyde Park, London, W.
1874. ‡Henry, Rev. P. Shuldam, D.D., M.R.I.A. Belfast.
*Henry, William Charles, M.D., F.R.S., F.G.S., F.R.G.S., F.C.S. Haffield, near Ledbury, Herefordshire.
1870. ‡Henty, William. 12 Medina-villas, Brighton.
1855. *Hepburn, J. Gotch, LL.B., F.C.S. Baldwyns, Bexley, Kent.
1855. ‡Hepburn, Robert. 9 Portland-place, London, W.
Hepburn, Thomas. Clapham, London, S.W.
1856. ‡*Hepworth, Rev. Robert. 2 St. James's-square, Cheltenham.*
1882. §Herbert, The Hon. Auberon. Ashley, Arnewood Farm, Lymington.
1866. ‡Herrick, Perry. Bean Manor Park, Loughborough.
1871. *Herschel, Professor Alexander S., B.A., F.R.A.S. College of Science, Newcastle-on-Tyne.
1874. §Herschel, Major John, R.E., F.R.S., F.R.A.S. Mussoorie, N. W. P. India. (Care of Messrs. H. Robertson & Co., 5 Crosby-square, London, E.C.)
1865. ‡Heslop, Dr. Birmingham.
1881. ‡Hey, Rev. William Croser, M.A. Clifton, York.
1882. §Heycock, Charles T., B.A. King's College, Cambridge.
1866. *Heymann, Albert. West Bridgford, Nottinghamshire.
1866. ‡Heymann, L. West Bridgford, Nottinghamshire.
1879. ‡Heywood, A. Percival. Duffield Bank, Derby.
1861. *Heywood, Arthur Henry. Elleray, Windermere.

Year of Election.

*HEYWOOD, JAMES, F.R.S., F.G.S., F.S.A., F.R.G.S., F.S.S. 26 Kensington Palace-gardens, London, W.
1861. *Heywood, Oliver. Claremont, Manchester.
Heywood, Thomas Percival. Claremont, Manchester.
1881. §Hick, Thomas, B.A., B.Sc. 2 George's-terrace, Harrogate.
1875. ‡HICKS, HENRY, M.D., F.G.S. Hendon Grove, Hendon, Middlesex, N.W.
1877. §HICKS, W. M., M.A. St. John's College, Cambridge.
1864. *HIERN, W. P., M.A. Castle House, Barnstaple.
1861. *Higgin, James. Lancaster-avenue, Fennel-street, Manchester.
1875. ‡Higgins, Charles Hayes, M.D., M.R.C.P., F.R.C.S., F.R.S.E. Alfred House, Birkenhead.
1871. ‡HIGGINS, CLEMENT, B.A., F.C.S. 103 Holland-road, Kensington, London, W.
1854. ‡HIGGINS, Rev. HENRY H., M.A. The Asylum, Rainhill, Liverpool.
1861. *Higgins, James. Holmwood, Turvey, near Bedford.
1870. ‡Higginson, Alfred. 135 Tulse Hill, London, S.W.
Hildyard, Rev. James, B.D., F.C.P.S. Ingoldsby, near Grantham, Lincolnshire.
Hill, Arthur. Bruce Castle, Tottenham, Middlesex.
1880. ‡Hill, Benjamin. Cwmdwr, near Clydach, Swansea.
1872. §Hill, Charles, F.S.A. Rockhurst, West Hoathley, East Grinstead.
*Hill, Rev. Canon, M.A., F.G.S. Sheering Rectory, Harlow.
1881. §HILL, Rev. EDWIN, M.A., F.G.S. St. John's College, Cambridge.
1857. §Hill, John, C.E., M.R.I.A., F.R.G.S.I. County Surveyor's Office, Ennis, Ireland.
1871. ‡Hill, Lawrence. The Knowe, Greenock.
1881. §Hill, Pearson. 50 Belsize Park, London, N.W.
1876. ‡Hill, William H. Barlanark, Shettleston, N.B.
1863. ‡Hills, F. C. Chemical Works, Deptford, Kent, S.E.
1871. *Hills, Thomas Hyde. 225 Oxford-street, London, W.
1858. ‡HINCKS, Rev. THOMAS, B.A., F.R.S. Stancliff House, Clevedon, Somerset.
1870. ‡HINDE, G. J., Ph.D., F.G.S. 11 Glebe Villas, Mitcham, Surrey.
*Hindmarsh, Luke. Alnbank House, Alnwick.
1865. ‡Hinds, James, M.D. Queen's College, Birmingham.
1863. ‡Hinds, William, M.D. Parade, Birmingham.
1881. §Hingston, J. T. Clifton, York.
1858. ‡Hirst, John, jun. Dobcross, near Manchester.
1861. *HIRST, T. ARCHER, Ph.D., F.R.S., F.R.A.S. Royal Naval College, Greenwich, S.E.; and Athenæum Club, Pall Mall, London, S.W.
1870. ‡Hitchman, William, M.D., LL.D., F.L.S. 29 Erskine-street, Liverpool.
*Hoare, Rev. Canon. Godstone Rectory, Redhill.
Hoare, J. Gurney. Hampstead, London, N.W.
1881. §Hobbes, Robert George. The Dockyard, Chatham.
1864. ‡Hobhouse, Arthur Fane. 24 Cadogan-place, London, S.W.
1864. ‡Hobhouse, Charles Parry. 24 Cadogan-place, London, S.W.
1864. ‡Hobhouse, Henry William. 24 Cadogan-place, London, S.W.
1879. §Hobkirk, Charles P., F.L.S. Huddersfield.
1879. §Hobson, John. Tapton Elms, Sheffield.
1877. ‡Hockin, Edward. Poughill, Stratton, Cornwall.
1877. ‡Hodge, Rev. John Mackey, M.A. 38 Tavistock-place, Plymouth.
1876. ‡Hodges, Frederick W. Queen's College, Belfast.

Year of Election.

1852. ‡Hodges, John F., M.D., F.C.S., Professor of Agriculture in Queen's College, Belfast.
1863. *Hodgkin, Thomas. Benwell Dene, Newcastle-on-Tyne.
1880. §Hodgkinson, W. R. Eaton, Ph.D. Science Schools, South Kensington Museum, London, S.W.
1873. *Hodgson, George. Thornton-road, Bradford, Yorkshire.
1873. ‡Hodgson, James. Oakfield, Manningham, Bradford, Yorkshire.
1863. ‡Hodgson, Robert. Whitburn, Sunderland.
1863. ‡Hodgson, R. W. North Dene, Gateshead.
1865. *Hofmann, August Wilhelm, M.D., LL.D., Ph.D., F.R.S., F.C.S. 10 Dorotheen Strasse, Berlin.
1854. *Holcroft, George. Byron's-court, St. Mary's-gate, Manchester.
1873. *Holden, Isaac. Oakworth House, near Keighley, Yorkshire.
1879. ‡Holland, Calvert Bernard. Ashdell, Broomhill, Sheffield.
1878. *Holland, Rev. F. W., M.A. Evesham.
*Holland, Philip H. 3 Heath-rise, Willow-road, Hampstead, London, N.W.
1865. ‡Holliday, William. New-street, Birmingham.
1866. *Holmes, Charles. 59 London-road, Derby.
1873. ‡Holmes, J. R. Southbrook Lodge, Bradford, Yorkshire.
1882. *Holmes, Thomas Vincent, F.G.S. 28 Croom's-hill, Greenwich, S.E.
1876. ‡Holms, Colonel William, M.P. 95 Cromwell-road, South Kensington, London, S.W.
1870. ‡Holt, William D. 23 Edge-lane, Liverpool.
1875. *Hood, John. The Elms, Cotham Hill, Bristol.
1847. ‡Hooker, Sir Joseph Dalton, K.C.S.I., K.C.B., M.D., D.C.L., LL.D., F.R.S., V.P.L.S., F.G.S., F.R.G.S. Royal Gardens, Kew, Surrey.
1865. *Hooper, John P. Coventry Park, Streatham, London, S.W.
1877. *Hooper, Samuel F., B.A. Tamworth House, Mitcham Common, Surrey.
1856. ‡Hooton, Jonathan. 80 Great Ducie-street, Manchester.
1842. Hope, Thomas Arthur. Stanton, Bebington, Cheshire.
1865. ‡Hopkins, J. S. Jesmond Grove, Edgbaston, Birmingham.
1882. *Hopkinson, Edward, D.Sc. 12 Queen Anne's-gate, London, S.W.
1870. *Hopkinson, John, M.A., D.Sc., F.R.S. 78 Holland-road, Kensington, London, W.
1871. *Hopkinson, John, F.L.S., F.G.S. 95 New Bond-street, London, W.; and Wansford House, Watford.
1858. ‡Hopkinson, Joseph, jun. Britannia Works, Huddersfield.
Hornby, Hugh. Sandown, Liverpool.
1876. *Horne, Robert R. 150 Hope-street, Glasgow.
1875. *Horniman, F. J. Surrey House, Forest Hill, London, S.E.
1854. ‡Horsfall, Thomas Berry. Bellamour Park, Rugeley.
1856. ‡Horsley, John H. 1 Ormond-terrace, Cheltenham.
1868. ‡Hotson, W. C. Upper King-street, Norwich.
Houghton, The Right Hon. Lord, M.A., D.C.L., F.R.S., F.R.G.S. Travellers' Club, London, S.W.
1858. ‡Hounsfield, James. Hemsworth, Pontefract.
Hovenden, W. F., M.A. Bath.
1879. *Howard, D. 60 Belsize Park, London, N.W.
1863. ‡Howard, Philip Henry. Corby Castle, Carlisle.
1882. §Howard, William Frederick, Assoc. Memb. Inst. C.E. 13 Cavendish-street, Chesterfield, Derbyshire.
1876. ‡Howatt, James. 146 Buchanan-street, Glasgow.
1857. ‡Howell, Henry H., F.G.S., Director of the Geological Survey of Scotland. Geological Survey Office, Victoria-street, Edinburgh.
1868. ‡Howell, Rev. Canon Hinds. Drayton Rectory, near Norwich.

Year of Election.

1865. *Howlett, Rev. Frederick, F.R.A.S. East Tisted Rectory, Alton, Hants.
1863. ‡Howorth, H. H. Derby House, Eccles, Manchester.
1854. ‡Howson, The Very Rev. J. S., D.D., Dean of Chester. Chester.
1870. ‡Hubback, Joseph. 1 Brunswick-street, Liverpool.
1835. *Hudson, Henry, M.D., M.R.I.A. Glenville, Fermoy, Co. Cork.
1842. §Hudson, Robert, F.R.S., F.G.S., F.L.S. Clapham Common, London, S.W.
1879. ‡Hudson, Robert S., M.D. Redruth, Cornwall.
1867. ‡Hudson, William H. H., M.A., Professor of Mathematics in King's College, London. 19 Bennet's-hill, Doctors' Commons, London, E.C.
1858. *Huggins, William, D.C.L. Oxon., LL.D. Camb., F.R.S., F.R.A.S. Upper Tulse Hill, Brixton, London, S.W.
1857. ‡Huggon, William. 30 Park-row, Leeds.
1871. *Hughes, George Pringle, J.P. Middleton Hall, Wooler, Northumberland.
1870. *Hughes, Lewis. Fenwick-court, Liverpool.
1876. *Hughes, Rev. Thomas Edward. Wallfield House, Reigate.
1868. §Hughes, T. M'K., M.A., F.G.S., Woodwardian Professor of Geology in the University of Cambridge.
1863. ‡*Hughes, T. W. 4 Hawthorne-terrace, Newcastle-on-Tyne.*
1865. ‡Hughes, W. R., F.L.S., Treasurer of the Borough of Birmingham. Birmingham.
1867. §Hull, Edward, M.A., F.R.S., F.G.S., Director of the Geological Survey of Ireland, and Professor of Geology in the Royal College of Science. 14 Hume-street, Dublin.
*Hulse, Sir Edward, Bart., D.C.L. 47 Portland-place, London, W.; and Breamore House, Salisbury.
1861. ‡Hume, Rev. Canon Abraham, D.C.L., LL.D., F.S.A. All Souls' Vicarage, Rupert-lane, Liverpool.
1878. ‡Humphreys, H. Castle-square, Carnarvon.
1880. ‡Humphreys, Noel A., F.S.S. Ravenhurst, Hook, Kingston-on-Thames.
1856. ‡Humphries, David James. 1 Keynsham-parade, Cheltenham.
1862. *Humphry, George Murray, M.D., F.R.S., Professor of Anatomy in the University of Cambridge. Grove Lodge, Cambridge.
1877. *Hunt, Arthur Roope, M.A., F.G.S. Southwood, Torquay.
1865. ‡Hunt, J. P. Gospel Oak Works, Tipton.
1864. ‡Hunt, W. 72 Pulteney-street, Bath.
1875. *Hunt, William. The Woodlands, Tyndall's Park, Clifton, Bristol.
Hunter, Andrew Galloway. Denholm, Hawick, N.B.
1868. ‡Hunter, Christopher. Alliance Insurance Office, North Shields.
1867. ‡Hunter, David. Blackness, Dundee.
1881. §Hunter, F. W. Newbottle, Fence Houses, Durham.
1881. ‡Hunter, Rev. John. 38 The Mount, York.
1869. *Hunter, Rev. Robert, F.G.S. Rose Villa, Forest-road, Loughton, Essex.
1879. §Huntington, A. K., F.C.S., Professor of Metallurgy in King's College, London. King's College, London, W.C.
1863. ‡Huntsman, Benjamin. West Retford Hall, Retford.
1869. ‡Hurst, George. Bedford.
1882. §Hurst, Walter. 156 Stanhope-street, Regent's Park, London, N.W.
1861. *Hurst, William John. Drumaness Mills, Ballynahinch, Lisburn, Ireland.
1870. ‡Hurter, Dr. Ferdinand. Appleton, Widnes, near Warrington.
Husband, William Dalla. May Bank, Bournemouth.

Year of Election.

1882. §Hussey, Captain E. R., R.E. 24 Waterloo-place, Southampton.
1876. ‡Hutchinson, John. 22 Hamilton Park-terrace, Glasgow.
1868. *Hutchison, Robert, F.R.S.E. 29 Chester-street, Edinburgh.
Hutton, Crompton. Putney Park, Surrey, S.W.
1864. *Hutton, Darnton. 14 Cumberland-terrace, Regent's Park, London, N.W.
1857. ‡Hutton, Henry D. 10 Lower Mountjoy-street, Dublin.
1861. *HUTTON, T. MAXWELL. Summerhill, Dublin.
1852. ‡HUXLEY, THOMAS HENRY, Ph.D., LL.D., F.R.S., F.L.S., F.G.S., Professor of Natural History in the Royal School of Mines. 4 Marlborough-place, London, N.W.
Hyde, Edward. Dukinfield, near Manchester.
1871. *Hyett, Francis A. Painswick House, Stroud, Gloucestershire.

1882. *I'Anson, James, F.G.S. Fairfield House, Darlington.
1879. ‡Ibbotson, H. J. 26 Collegiate-crescent, Sheffield.
Ihne, William, Ph.D. Heidelberg.
1873. §Ikin, J. I. 19 Park-place, Leeds.
1861. ‡Iles, The Ven. Archdeacon, M.A. The Close, Lichfield.
1858. ‡Ingham, Henry. Wortley, near Leeds.
1876. ‡Inglis, Anthony. Broomhill, Partick, Glasgow.
1871. ‡INGLIS, The Right Hon. JOHN, D.C.L., LL.D., Lord Justice-General of Scotland. Edinburgh.
1876. ‡Inglis, John, jun. Prince's-terrace, Dowanhill, Glasgow.
1852. ‡INGRAM, J. K., LL.D., M.R.I.A., Regius Professor of Greek in the University of Dublin. 2 Wellington-road, Dublin.
1882. §Irving, Rev. A., B.A. Wellington College, Wokingham, Berks.
1862. ‡ISELIN, J. F., M.A., F.G.S. South Kensington Museum, London, S.W.
1881. §Ishiguro, Isoji. The Japanese Legation, 9 Cavendish-square, London, W.

1865. ‡*Jabet, George. Wellington-road, Handsworth, Birmingham.*
1870. ‡Jack, James. 26 Abercromby-square, Liverpool.
1859. ‡Jack, John, M.A. Belhelvie-by-Whitecairns, Aberdeenshire.
1876. ‡*Jack, William. 19 Lansdowne-road, Notting Hill, London, W.*
1879. ‡Jackson, Arthur, F.R.C.S. Wilkinson-street, Sheffield.
1874. **Jackson, Frederick Arthur. Cheadle, Cheshire.*
1866. ‡Jackson, H. W., F.R.A.S., F.G.S. 15 The Terrace, High-road, Lewisham, S.E.
1869. §Jackson, Moses. The Vale, Ramsgate.
1863. *Jackson-Gwilt, Mrs. H. Moonbeam Villa, The Grove, New Wimbledon, Surrey.
1874. *Jaffe, John. Edenvale, Strandtown, near Belfast.
1865 *Jaffray, John. Park-grove, Edgbaston, Birmingham.
1872. ‡James, Christopher. 8 Laurence Pountney Hill, London, E.C.
1860. ‡James, Edward H. Woodside, Plymouth.
1863. *JAMES, Sir WALTER, Bart., F.G.S. 6 Whitehall-gardens, London, S.W.
1858. ‡James, William C. Woodside, Plymouth.
1881. ‡Jamieson, Andrew, Principal of the College of Science and Arts, Glasgow.
1876. ‡Jamieson, J. L. K. The Mansion House, Govan, Glasgow.
1859. *Jamieson, Thomas F., F.G.S. Ellon, Aberdeenshire.
1850. ‡Jardine, Alexander. Jardine Hall, Lockerby, Dumfriesshire.
1870. ‡Jardine, Edward. Beach Lawn, Waterloo, Liverpool.
1853. *Jarratt, Rev. Canon J., M.A. North Cave, near Brough, Yorkshire.

Year of Election.

1870. ‡Jarrold, John James. London-street, Norwich.
1862. ‡Jeakes, Rev. James, M.A. 54 Argyll-road, Kensington, London, W.
Jebb, Rev. John. Peterstow Rectory, Ross, Herefordshire.
1856. §JEFFERY, HENRY M., M.A., F.R.S. 9 Dunstanville-terrace, Falmouth.
1855. *Jeffray, John. Cardowan House, Millerston, Glasgow.
1867. ‡Jeffreys, Howel, M.A., F.R.A.S. 5 Brick-court, Temple, London, E.C.
1861. *JEFFREYS, J. GWYN, LL.D., F.R.S., F.L.S., F.G.S. 1 The Terrace, Kensington, London, W.
1852. ‡JELLETT, Rev. JOHN H., B.D., M.R.I.A., Provost of Trinity College, Dublin.
1881. §JELLICOE, C. W. A. Southampton.
1862. §JENKIN, H. C. FLEEMING, F.R.S., M.I.C.E., Professor of Civil Engineering in the University of Edinburgh. 3 Great Stuart-street, Edinburgh.
1873. §Jenkins, Major-General J. J. 14 St. James's-square, London, S.W.
1880. *JENKINS, Sir JOHN JONES, M.P. The Grange, Swansea.
Jennette, Matthew. 106 Conway-street, Birkenhead.
1852. ‡Jennings, Francis M., F.G.S., M.R.I.A. Brown-street, Cork.
1872. ‡Jennings, W. Grand Hotel, Brighton.
1878. ‡Jephson, Henry L. Chief Secretary's Office, The Castle, Dublin.
*Jerram, Rev. S. John, M.A. Chobham Vicarage, Woking Station, Surrey.
1872. ‡Jesson, Thomas. 7 Upper Wimpole-street, Cavendish-square, London, W.
Jessop, William, jun. Butterley Hall, Derbyshire.
1871. *Johnson, David, F.C.S., F.G.S. Barrelwell House, Chester.
1881. ‡Johnson, Captain Edmond Cecil. 12 Cadogan-place, London, S.W.
1854. Johnson, Edward. 22 Talbot-street, Southport.
1865. *Johnson, G. J. 36 Waterloo-street, Birmingham.
1875. §Johnson, James Henry, F.G.S., F.S.A. 73 Albert-road, Southport.
1866. ‡Johnson, John G. 18A Basinghall-street, London, E.C.
1872. ‡Johnson, J. T. 27 Dale-street, Manchester.
1861. ‡Johnson, Richard. 27 Dale-street, Manchester.
1870. ‡Johnson, Richard C., F.R.A.S. 19 Catherine-street, Liverpool.
1863. ‡Johnson, R. S. Hanwell, Fence Houses, Durham.
1881. §Johnson, Samuel George. Municipal Offices, Nottingham.
1861. ‡Johnson, William Beckett. Woodlands Bank, near Altrincham.
1864. ‡Johnston, David. 13 Marlborough-buildings, Bath.
1859. ‡Johnston, James. Newmill, Elgin, N.B.
1864. ‡Johnston, James. Manor House, Northend, Hampstead, London, N.W.
*Johnstone, James. Alva House, Alva, by Stirling, N.B.
1864. ‡Johnstone, John. 1 Barnard-villas, Bath.
1876. ‡Johnstone, William. 5 Woodside-terrace, Glasgow.
1864. ‡Jolly, Thomas. Park View-villas, Bath.
1871. §JOLLY, WILLIAM, F.R.S.E., F.G.S., H.M. Inspector of Schools. Inverness, N.B.
1881. §Jones, Alfred Orlando, M.D. Belton House, Harrogate.
1849. ‡Jones, Baynham. Selkirk Villa, Cheltenham.
1856. ‡Jones, C. W. 7 Grosvenor-place, Cheltenham.
1877. ‡Jones, Henry C., F.C.S. 166 Blackstock-road, London, N.
1881. §Jones, J. Viriamu. Firth College, Sheffield.
1873. ‡Jones, Theodore B. 1 Finsbury-circus, London, E.C.

Year of
Election.

1880. §Jones, Thomas. 15 Gower-street, Swansea.
1860. ‡JONES, THOMAS RUPERT, F.R.S., F.G.S. 10 Ulverdale-road, King's-road, Chelsea, London, S.W.
1864. ‡JONES, Sir WILLOUGHBY, Bart., F.R.G.S. Cranmer Hall, Fakenham, Norfolk.
1875. *Jose, J. E. 3 Queen-square, Bristol.
*Joule, Benjamin St. John B., J.P. 28 Leicester-street, Southport, Lancashire.
1842. *JOULE, JAMES PRESCOTT, LL.D., F.R.S., F.C.S. 12 Wardle-road, Sale, near Manchester.
1847. ‡JOWETT, Rev. B., M.A., Regius Professor of Greek in the University of Oxford. Balliol College, Oxford.
1858. ‡Jowett, John. Leeds.
1879. ‡Jowitt, A. Hawthorn Lodge, Clarkehouse-road, Sheffield.
1872. ‡Joy, Algernon. Junior United Service Club, St. James's, London, S.W.
1848. *Joy, Rev. Charles Ashfield. Grove Parsonage, Wantage, Berkshire.
Joy, Rev. John Holmes, M.A. 3 Coloney-terrace, Tunbridge Wells.
*Jubb, Abraham. Halifax.
1870. ‡JUDD, JOHN WESLEY, F.R.S., F.G.S., Professor of Geology in the Royal School of Mines. Hurstleigh, Kew.

1868. *Kaines, Joseph, M.A., D.Sc. 40 Finsbury-pavement, London, E.C.
KANE, Sir ROBERT, M.D., LL.D., F.R.S., M.R.I.A., F.C.S., Principal of the Royal College of Cork. Fortland, Killiney, Co. Dublin.
1857. ‡Kavanagh, James W. Grenville, Rathgar, Ireland.
1859. ‡Kay, David, F.R.G.S. 19 Upper Phillimore-place, Kensington, London, W.
Kay, John Cunliff. Fairfield Hall, near Skipton.
Kay, Robert. Haugh Bank, Bolton-le-Moors.
1847. *Kay, Rev. William, D.D. Great Leghs Rectory, Chelmsford.
1872. ‡*Keames, William M. 5 Lower Rock-gardens, Brighton.*
1875. ‡Keeling, George William. Tuthill, Lydney.
1881. §Keeping, Walter, M.A., F.G.S. The Museum, York.
1878. *Kelland, William Henry. 110 Jermyn-street, London, S.W.; and Grettans, Bow, North Devon.
1876. ‡Kelly, Andrew G. The Manse, Alloa, N.B.
1864. *Kelly, W. M., M.D. 11 The Crescent, Taunton, Somerset.
1853. ‡Kemp, Rev. Henry William, B.A. The Charter House, Hull.
1875. ‡KENNEDY, ALEXANDER B. W., C.E., Professor of Engineering in University College, London.
1876. ‡Kennedy, Hugh. Redclyffe, Partickhill, Glasgow.
Kent, J. C. Levant Lodge, Earl's Croome, Worcester.
1857. ‡Kent, William T., M.R.D.S. 51 Rutland-square, Dublin.
1857. *Ker, André Allen Murray. Newbliss House, Newbliss, Ireland.
1855. *Ker, Robert. Dougalston, Milngavie, N.B.
1876. ‡Ker, William. 1 Windsor-terrace West, Glasgow.
1881. §Kermode, Philip M. C. Ramsay, Isle of Man.
1868. ‡Kerrison, Roger. Crown Bank, Norwich.
1869. *Kesselmeyer, Charles A. 1 Peter-street, Manchester.
1869. *Kesselmeyer, William Johannes. 1 Peter-street, Manchester.
1861. *Keymer, John. Parker-street, Manchester.
1876. ‡Kidston, J. B. West Regent-street, Glasgow.
1876. ‡Kidston, William. Ferniegair, Helensburgh, N.B.
1865. *Kinahan, Edward Hudson, M.R.I.A. 11 Merrion-square North, Dublin.

Year of Election.

1878. ‡Kinahan, Edward Hudson, jun. 11 Merrion-square North, Dublin.
1860. ‡KINAHAN, G. HENRY, M.R.I.A. Geological Survey of Ireland, 14 Hume-street, Dublin.
1875. *Kinch, Edward, F.C.S. Agricultural College, Cirencester.
1872. *King, Mrs. E. M. 34 Cornwall-road, Westbourne Park, London, W.
1875. *King, F. Ambrose. Avonside, Clifton, Bristol.
1871. *King, Herbert Poole. Theological College, Salisbury.
1855. ‡King, James. Levernholme, Hurlet, Glasgow.
1870. §King, John Thomson, C.E. 4 Clayton-square, Liverpool.
King, Joseph. Welford House, Greenhill, Hampstead, London, N.W.
1864. §KING, KELBURNE, M.D. 27 George-street, and Royal Institution, Hull.
1860. *King, Mervyn Kersteman. 1 Vittoria-square, Clifton, Bristol.
1875. *King, Percy L. Avonside, Clifton, Bristol.
1870. ‡King, William. 13 Adelaide-terrace, Waterloo, Liverpool.
King, William Poole, F.G.S. Avonside, Clifton, Bristol.
1869. ‡Kingdon, K. Taddiford, Exeter.
1861. ‡Kingsley, John. Ashfield, Victoria Park, Manchester.
1876. §Kingston, Thomas. 9 Houghton-place, Ampthill-square, London, N.W.
1835. Kingstone, A. John, M.A. Mosstown, Longford, Ireland.
1875. §KINGZETT, CHARLES T., F.C.S. 17 Lansdowne-road, Tottenham, Middlesex.
1867. ‡Kinloch, Colonel. Kirriemuir, Logie, Scotland.
1867. *KINNAIRD, The Right Hon. Lord. 2 Pall Mall East, London, S.W.; and Rossie Priory, Inchture, Perthshire.
1870. ‡Kinsman, William R. Branch Bank of England, Liverpool.
1863. ‡*Kirkaldy, David. 28 Bartholomew-road North, London, N.W.*
1860. ‡KIRKMAN, Rev. THOMAS P., M.A., F.R.S. Croft Rectory, near Warrington.
Kirkpatrick, Rev. W. B., D.D. 48 North Great George-street, Dublin.
1876. *Kirkwood, Anderson, LL.D., F.R.S.E. 7 Melville-terrace, Stirling, N.B.
1875. ‡Kirsop, John. 6 Queen's-crescent, Glasgow.
1870. ‡Kitchener, Frank E. Newcastle, Staffordshire.
1881. ‡Kitching, Langley. 50 Caledonian-road, Leeds.
1869. ‡Knapman, Edward. The Vineyard, Castle-street, Exeter.
1870. ‡Kneeshaw, Henry. 2 Gambier-terrace, Liverpool.
1836. Knipe, J. A. Botcherby, Carlisle.
1872. *Knott, George, LL.B., F.R.A.S. Knowles Lodge, Cuckfield, Hayward's Heath, Sussex.
1873. *Knowles, George. Moorhead, Shipley, Yorkshire.
1872. ‡Knowles, James. The Hollies, Clapham Common, S.W.
1842. *Knowles, John. The Lawn, Rugby.*
1870. ‡Knowles, Rev. J. L. 103 Earl's Court-road, Kensington, London, W.
1874. ‡Knowles, William James. Flixton-place, Ballymena, Co. Antrim.
1876. ‡Knox, David N., M.A., M.B. 8 Belgrave-terrace, Hillhead, Glasgow.
*Knox, George James. 2 Coleshill-street, Eaton-square, London, S.W.
1835. *Knox, Thomas Perry. Union Club, Trafalgar-square, London, W.C.*
1875. *Knubley, Rev. E. P. Staveley Rectory, Leeds.
1881. ‡Kurobe, Hiroo. Legation of Japan, 9 Cavendish-square, London, W.
1870. ‡Kynaston, Josiah W., F.C.S. St. Helen's, Lancashire.

Year of Election.

1865. ‡Kynnersley, J. C. S. The Leveretts, Handsworth, Birmingham
1882. §Kyshe, John B. 19 Royal-avenue, Sloane-square, London, S.W.

1858. §Lace, Francis John. Stone Gapp, Cross-hill, Leeds.
1859. §Ladd, William, F.R.A.S. Claremont Villa, Rectory-road, Beckenham, Kent.
1870. ‡Laird, H. H. Birkenhead.
1882. §Lake, G. A. K., M.D. East Park-terrace, Southampton.
1870. §Laird, John, jun. Grosvenor-road, Claughton, Birkenhead.
1880. *Lake, Samuel. Milford Docks, Milford Haven.
1877. §Lake, W. C., M.D. Teignmouth.
1859. ‡Lalor, John Joseph, M.R.I.A. 2 Longford-terrace, Monkstown, Co. Dublin.
1871. ‡Lancaster, Edward. Karesforth Hall, Barnsley, Yorkshire.
1877. ‡Landon, Frederic George, M.A., F.R.A.S. 8 The Circus, Greenwich, London, S.E.
1859. ‡Lang, Rev. John Marshall, D.D. Barony, Glasgow.
1864. ‡Lang, Robert. Langford Lodge, College-road, Clifton, Bristol.
1882. §Langstaff, Dr. Bassett, Southampton.
1870. ‡Langton, Charles. Barkhill, Aigburth, Liverpool.
*Langton, William. Docklands, Ingatestone, Essex.
1865. ‡Lankester, E. Ray, M.A., F.R.S., Professor of Comparative Anatomy and Zoology in University College, London. 11 Wellington Mansions, North Bank, London, N.W.
1880. *Lansdell, Rev. Henry. Eyre Cottage, Blackheath, London, S.E.
Lanyon, Sir Charles. The Abbey, White Abbey, Belfast.
1878. ‡Lapper, E., M.D. 61 Harcourt-street, Dublin.
1881. ‡Larmor, Joseph, M.A., Professor of Natural Philosophy in Queen's College, Galway.
1870. *Latham, Baldwin, C.E., F.G.S. 7 Westminster-chambers, Westminster, S.W.
1870. ‡Laughton, John Knox, M.A., F.R.A.S., F.R.G.S. Royal Naval College, Greenwich, S.E.
1870. *Law, Channell. Sydney Villa, 36 Outram-road, Addiscombe, Croydon.
1878. ‡Law, Henry, C.E. 5 Queen Anne's-gate, London, S.W.
1857. ‡Law, Hugh, Q.C. 9 Fitzwilliam-square, Dublin.
1862. ‡Law, Rev. James Edmund, M.A. Little Shelford, Cambridgeshire.
Lawley, The Hon. Francis Charles. Escrick Park, near York.
Lawley, The Hon. Stephen Willoughby. Escrick Park, near York.
1870. ‡Lawrence, Edward. Aigburth, Liverpool.
1881. §Lawrence, Rev. F., B.A. St. Mary's Rectory, Castlegate, York.
1875. ‡Lawson, George, Ph.D., LL.D., Professor of Chemistry and Botany. Halifax, Nova Scotia.
1857. ‡Lawson, The Right Hon. James A., LL.D., M.R.I.A. 27 Fitzwilliam-street, Dublin.
1868. *Lawson, M. Alexander, M.A., F.L.S., Professor of Botany in the University of Oxford. Botanic Gardens, Oxford.
1863. ‡*Lawton, Benjamin C. Neville Chambers, 44 Westgate-street, Newcastle-upon-Tyne.*
1853. ‡Lawton, William. 5 Victoria-terrace, Derringham, Hull.
1865. ‡Lea, Henry. 35 Paradise-street, Birmingham.
1857. ‡Leach, Colonel R. E. Mountjoy, Phœnix Park, Dublin.
1870. *Leaf, Charles John, F.L.S., F.G.S., F.S.A. Old Change, London, E.C.; and Painshill, Cobham.

Year of Election.

1847. *LEATHAM, EDWARD ALDAM, M.P. Whitley Hall, Huddersfield; and 46 Eaton-square, London, S.W.
1844. *Leather, John Towlerton, F.S.A. Leventhorpe Hall, near Leeds.
1858. ‡*Leather, John W. Newton-green, Leeds.*
1863. ‡Leavers, J. W. The Park, Nottingham.
1872. ‡LEBOUR, G. A., M.A., F.G.S., Professor of Geology in the College of Physical Science, Newcastle-on-Tyne.
1858. *Le Cappelain, John. Wood-lane, Highgate, London, N.
1861. ‡Lee, Henry. Irwell House, Lower Broughton, Manchester.
1853. *LEE, JOHN EDWARD, F.G.S., F.S.A. Villa Syracusa, Torquay.
1882. §Lees, R. W. Moira-place, Southampton.
1859. ‡*Lees, William. Link Vale Lodge, Viewforth, Edinburgh.*
*Leese, Joseph. Glenfield, Altrincham, Manchester.
1881. §LE FEUVRE, J. E. Southampton.
1872. ‡LEFEVRE, The Right Hon. G. SHAW, M.P., F.R.G.S. 18 Bryanston-square, London, W.
*LEFROY, Lieut.-General Sir JOHN HENRY, C.B., K.C.M.G., R.A., F.R.S., F.R.G.S. 82 Queen's-gate, London, S.W.
*Legh, Lieut.-Colonel George Cornwall. High Legh Hall, Cheshire.
1869. ‡Le Grice, A. J. Trereife, Penzance.
1868. ‡LEICESTER, The Right Hon. the Earl of, K.G. Holkham, Norfolk.
1856. ‡LEIGH, The Right Hon. Lord, D.C.L. 37 Portman-square, London, W.; and Stoneleigh Abbey, Kenilworth.
1861. *Leigh, Henry. Moorfield, Swinton, near Manchester.
1870. ‡Leighton, Andrew. 35 High-park-street, Liverpool.
1880. §Leighton, William Henry, F.G.S. 2 Merton-place, Chiswick.
1867. §Leishman, James. Gateacre Hall, Liverpool.
1870. ‡Leister, G. F. Gresbourn House, Liverpool.
1859. ‡Leith, Alexander. Glenkindie, Inverkindie, N.B.
1882. §Lemon, James, M.I.C.E. 11 The Avenue, Southampton.
1863. *LENDY, Major AUGUSTE FREDERIC, F.L.S., F.G.S. Sunbury House, Sunbury, Middlesex.
1867. ‡Leng, John. 'Advertiser' Office, Dundee.
1878. ‡Lennon, Rev. Francis. The College, Maynooth, Ireland.
1861. ‡Lennox, A. C. W. 7 Beaufort-gardens, Brompton, London, S.W.
Lentaigne, Sir John, C.B., M.D. Tallaght House, Co. Dublin; and 1 Great Denmark-street, Dublin.
Lentaigne, Joseph. 12 Great Denmark-street, Dublin.
1871. ‡LEONARD, HUGH, F.G.S., M.R.I.A., F.R.G.S.I. St. David's, hide-road, Co. Dublin.
1874. ‡Lepper, Charles W. Laurel Lodge, Belfast.
1861. ‡Leppoc, Henry Julius. Kersal Crag, near Manchester.
1872. ‡Lermit, Rev. Dr. School House, Dedham.
1871. ‡Leslie, Alexander, C.E. 72 George-street, Edinburgh.
1880. ‡LETCHER, R. J. Lansdowne-terrace, Walters-road, Swansea.
1866. §LEVI, Dr. LEONE, F.S.A., F.S.S., F.R.G.S., Professor of Commercial Law in King's College, London. 5 Crown Office-row, Temple, London, E.C.
1879. ‡Lewin, Lieut.-Colonel. Tanhurst, Dorking.
1870. ‡LEWIS, ALFRED LIONEL. 35 Colebrooke-row, Islington, London, N.
1853. ‡Liddell, George William Moore. Sutton House, near Hull.
1860. ‡LIDDELL, The Very Rev. H. G., D.D., Dean of Christ Church, Oxford.
1876. ‡Lietke, J. O. 30 Gordon-street, Glasgow.
1862. ‡LILFORD, The Right Hon. Lord, F.L.S. Lilford Hall, Oundle, Northamptonshire.

Year of Election.

*LIMERICK, The Right Rev. CHARLES GRAVES, D.D., F.R.S., M.R.I.A., Lord Bishop of. The Palace, Henry-street, Limerick.
1878. ‡Lincolne, William. Ely, Cambridgeshire.
1881. *Lindley, William, C.E., F.G.S. 10 Kidbrooke-terrace, Blackheath, London, S.E.
*Lindsay, Charles. Ridge Park, Lanark, N.B.
1870. ‡*Lindsay, Thomas, F.C.S. 288 Renfrew-street, Glasgow.*
1871. ‡Lindsay, Rev. T. M., M.A., D.D. Free Church College, Glasgow.
Lingwood, Robert M., M.A., F.L.S., F.G.S. 1 Derby-villas, Cheltenham.
1876. §Linn, James. Geological Survey Office, India-buildings, Edinburgh.
1882. *Lister, Rev. Henry, B.A. Hawridge Rectory, Berkhampstead.
1870. §Lister, Thomas. Victoria-crescent, Barnsley, Yorkshire.
1876. ‡Little, Thomas Evelyn. 42 Brunswick-street, Dublin.
Littledale, Harold. Liscard Hall, Cheshire.
1881. §Littlewood, Rev. B. C., B.A. Holmdale, Cheltenham.
1861. *LIVEING, G. D., M.A., F.R.S., F.C.S., Professor of Chemistry in the University of Cambridge. Cambridge.
1876. *Liversidge, Archibald, F.R.S., F.C.S., F.G.S., F.R.G.S., Professor of Geology and Mineralogy in the University of Sydney, N.S.W. (Care of Messrs. Trübner & Co., Ludgate Hill, London, E.C.)
1864. §Livesay, J. G. Cromarty House, Ventnor, Isle of Wight.
1880. ‡Llewelyn, John T. D. Penllegare, Swansea.
Lloyd, Rev. A. R. Hengold, near Oswestry.
1842. Lloyd, Edward. King-street, Manchester.
1865. ‡Lloyd, G. B. Edgbaston-grove, Birmingham.
*Lloyd, George, M.D., F.G.S. Acock's-green, near Birmingham.
1865. ‡Lloyd, John. Queen's College, Birmingham.
Lloyd, Rev. Rees Lewis. Belper, Derbyshire.
1877. *Lloyd, Sampson Samuel. Moor Hall, Sutton Coldfield.
1865. *Lloyd, Wilson, F.R.G.S. Myrod House, Wednesbury.
1854. *LOBLEY, JAMES LOGAN, F.G.S., F.R.G.S. 59 Clarendon-road, Kensington Park, London, W.; and New Athenæum Club, S.W.
1853. *Locke, John. 133 Leinster-road, Dublin.
1867. *Locke, John. 83 Addison-road, Kensington, London, W.
1863. ‡LOCKYER, J. NORMAN, F.R.S., F.R.A.S. 16 Penywern-road, South Kensington, London, S.W.
1875. *LODGE, OLIVER J., D.Sc. 26 Waverley-road, Sefton Park, Liverpool.
1868. ‡Login, Thomas, C.E., F.R.S.E. India.
1862. ‡Long, Andrew, M.A. King's College, Cambridge.
1876. ‡Long, H. A. Charlotte-street, Glasgow.
1872. ‡Long, Jeremiah. 50 Marine Parade, Brighton.
1871. *Long, John Jex. 727 Duke-street, Glasgow.
1851. ‡Long, William, F.G.S. Hurts Hall, Saxmundham, Suffolk.
1866. §Longdon, Frederick. Osmaston-road, Derby.
LONGFIELD, The Right Hon. MOUNTIFORT, LL.D., M.R.I.A., Regius Professor of Feudal and English Law in the University of Dublin. 47 Fitzwilliam-square, Dublin.
1859. ‡Longmuir, Rev. John, M.A., LL.D. 14 Silver-street, Aberdeen.
1875. *Longstaff, George Blundell, M.A., M.B., F.C.S. Southfield Grange, Wandsworth, S.W.
1871. §Longstaff, George Dixon, M.D., F.C.S. Southfields, Wandsworth, S.W.; and 9 Upper Thames-street, London, E.C.
1872. *Longstaff, Lieut.-Colonel Llewellyn Wood, F.R.G.S. Ridgelands, Wimbledon, Surrey.
1881. *Longstaff, Mrs. Ll. W. Ridgelands, Wimbledon, Surrey.

Year of Election.

1861. *Lord, Edward. Adamroyd, Todmorden.
1863. ‡Losh, W. S. Wreay Syke, Carlisle.
1876. *Love, James, F.R.A.S. 27 Bickerton-road, Upper Holloway, London, N.
1875. *Lovett, W. J. 96 Lionel-street, Birmingham.
1867. *Low, James F. Monifieth, by Dundee.
1863. *Lowe, Lieut.-Colonel Arthur S. H., F.R.A.S. 76 Lancaster-gate, London, W.
1861. *LOWE, EDWARD JOSEPH, F.R.S., F.R.A.S., F.L.S., F.G.S., F.M.S. Shirenewton, near Chepstow.
1870. ‡Lowe, G. C. 67 Cecil-street, Greenheys, Manchester.
1868. ‡Lowe, John, M.D. King's Lynn.
1850. ‡Lowe, William Henry, M.D., F.R.S.E. Balgreen, Slateford, Edinburgh.
1881. ‡Lubbock, Arthur Rolfe. High Elms, Hayes, Kent.
1853. *LUBBOCK, Sir JOHN, Bart., M.P., D.C.L., LL.D., F.R.S., Pres. L.S., F.G.S. 34 Queen Anne's-gate, London, S.W.; and High Elms, Hayes, Kent.
1881. ‡Lubbock, John B. High Elms, Hayes, Kent.
1870. ‡Lubbock, Montague, M.D. 19 Grosvenor-street, London, W.
1878. ‡Lucas, Joseph. Tooting Graveney, London, S.W.
1849. *Luckcock, Howard. Oak-hill, Edgbaston, Birmingham.
1875. §Lucy, W. C., F.G.S. The Winstones, Brookthorpe, Gloucester.
1881. ‡Luden, C. M. 4 Bootham-terrace, York.
1867. *Luis, John Henry. Cidhmore, Dundee.
1873. ‡Lumley, J. Hope Villa, Thornbury, near Bradford, Yorkshire.
1866. *Lund, Charles. 48 Market-street, Bradford, Yorkshire.
1873. ‡Lund, Joseph. Ilkley, Yorkshire.
1850. *Lundie, Cornelius. Teviot Bank, Newport Road, Cardiff.
1853. ‡Lunn, William Joseph, M.D. 23 Charlotte-street, Hull.
1858. *Lupton, Arthur. Headingley, near Leeds.
1864. *Lupton, Darnton. The Harehills, near Leeds.
1874. *Lupton, Sydney, M.A. Harrow.
1864. *Lutley, John. Brockhampton Park, Worcester.
1871. ‡Lyell, Leonard, F.G.S. 92 Onslow-gardens, London, S.W.
1874. ‡Lynam, James, C.E. Ballinasloe, Ireland.
1857. ‡Lyons, Robert D., M.B., M.R.I.A. 8 Merrion-square West, Dublin.
1878. ‡Lyte, Cecil Maxwell. Cotford, Oakhill-road, Putney, S.W.
1862. *LYTE, F. MAXWELL, F.C.S. Cotford, Oakhill-road, Putney, S.W.

1852. ‡McAdam, Robert. 18 College-square East, Belfast.
1854. *MACADAM, STEVENSON, Ph.D., F.R.S.E., F.C.S., Lecturer on Chemistry. Surgeons' Hall, Edinburgh; and Brighton House, Portobello, by Edinburgh.
1876. *MACADAM, WILLIAM IVISON. Surgeons' Hall, Edinburgh.
1868. ‡MACALISTER, ALEXANDER, M.D., F.R.S., Professor of Zoology in the University of Dublin. 13 Adelaide-road, Dublin.
1878. §MacAlister, Donald, M.A., M.B., B.Sc. St. John's College, Cambridge.
1879. §MacAndrew, James J. Lukesland, Ivybridge, South Devon.
1866. *M'Arthur, A., M.P. Raleigh Hall, Brixton Rise, London, S.W.
1838. Macaulay, Henry. 14 Clifton Bank, Rotherham, Yorkshire.
1840. MACAULAY, JAMES, A.M., M.D. 25 Carlton-road, Maida Vale, London, N.W.
1871. ‡*M'Bain, James, M.D., R.N. Logie Villa, York-road, Trinity, Edinburgh.*

Year of Election.

*MacBrayne, Robert. Messrs. Black and Wingate, 5 Exchange-square, Glasgow.
1866. ‡M'CALLAN, Rev. J. F., M.A. Basford, near Nottingham.
1863. ‡M'Calmont, Robert. Gatton Park, Reigate.
1855. ‡M'Cann, Rev. James, D.D., F.G.S. 8 Oak-villas, Lower Norwood, Surrey, S.E.
1876. *M'CLELLAND, A. S. 4 Crown-gardens, Dowanhill, Glasgow.
1868. ‡M'CLINTOCK, Rear-Admiral Sir FRANCIS L., R.N., F.R.S., F.R.G.S. United Service Club, Pall Mall, London, S.W.
1872. *M'Clure, J. H. The Wilderness, Richmond, Surrey.
1874. ‡M'Clure, Sir Thomas, Bart. Belmont, Belfast.
1878. *M'Comas, Henry. Homestead, Dundrum, Co. Dublin.
1859. *M'Connell, David C., F.G.S. Care of Mr. H. K. Lewis, 136 Gower-street, London, W.C.
1858. ‡M'Connell, J. E. Woodlands, Great Missenden.
1876. ‡M'Culloch, Richard. 109 Douglas-street, Blythswood-square, Glasgow.
1871. ‡*M'Donald, William. Yokohama, Japan. (Care of R. K. Knevitt, Esq., Sun-court, Cornhill, E.C.)*
1878. ‡McDonnell, Alexander. St. John's, Island Bridge, Dublin.
MacDonnell, Hercules H. G. 2 Kildare-place, Dublin.
1878. ‡McDonnell, James. 32 Upper Fitzwilliam-street, Dublin.
1878. ‡McDonnell, Robert, M.D., F.R.S., M.R.I.A. Merrion-square, Dublin.
*M'Ewan, John. 4 Douglas-terrace, Stirling, N.B.
1881. ‡Macfarlane, A., D.Sc., F.R.S.E. The University, Edinburgh.
1871. ‡M'Farlane, Donald. The College Laboratory, Glasgow.
1855. *Macfarlane, Walter. 22 Park-circus, Glasgow.
1879. ‡Macfarlane, Walter, jun. 22 Park-circus, Glasgow.
1854. *Macfie, Robert Andrew. Dreghorn, Colinton, Edinburgh.
1867. *M'Gavin, Robert. Ballumbie, Dundee.
1855. ‡MacGeorge, Andrew, jun. 21 St. Vincent-place, Glasgow.
1872. ‡M'George, Mungo. Nithsdale, Laurie Park, Sydenham, S.E.
1873. ‡McGowen, William Thomas. Oak-avenue, Oak Mount, Bradford, Yorkshire.
1855. ‡*MacGregor, James Watt. 2 Laurence-place, Partick, Glasgow.*
1876. ‡M'Grigor, Alexander B., LL.D. 19 Woodside-terrace, Glasgow.
1859. ‡M'Hardy, David. 54 Netherkinkgate, Aberdeen.
1874. ‡MacIlwaine, Rev. Canon, D.D., M.R.I.A. Ulsterville, Belfast.
1859. ‡*Macintosh, John. Middlefield House, Woodside, Aberdeen.*
1867. *M'INTOSH, W. C., M.D., LL.D., F.R.S. L. & E., F.L.S. Murthly, Perthshire.
1854. *MacIver, Charles. 8 Abercromby-square, Liverpool.
1871. ‡Mackay, Rev. A., LL.D., F.R.G.S. 2 Hatton-place, Grange, Edinburgh.
1873. ‡McKENDRICK, JOHN G., M.D., F.R.S.E., Professor of the Institutes of Medicine in the University of Glasgow, and Fullerian Professor of Physiology in the Royal Institution, London.
1880. *Mackenzie, Colin. Junior Athenæum Club, Piccadilly, London, W.
1865. ‡Mackeson, Henry B., F.G.S. Hythe, Kent.
1872. *Mackey, J. A. 24 Buckingham-place, Brighton.
1867. ‡*Mackie, Samuel Joseph, C.E., F.G.S. 22 Eldon-road, Kensington, London, W.*
*Mackinlay, David. 6 Great Western-terrace, Hillhead, Glasgow.
1865. ‡Mackintosh, Daniel, F.G.S. Whitford-road, Tranmere, Birkenhead.
1850. ‡Macknight, Alexander. 20 Albany-street, Edinburgh.
1867. ‡Mackson, H. G. 25 Cliff-road, Woodhouse, Leeds.

Year of Election.

1872. *McLachlan, Robert, F.R.S., F.L.S. 39 Limes-grove, Lewisham, S.E.

1873. ‡McLandsborough, John, C.E., F.R.A.S., F.G.S. South Park Villa, Harrogate, Yorkshire.

1860. ‡Maclaren, Archibald. Summertown, Oxfordshire.

1864. ‡MacLaren, Duncan. Newington House, Edinburgh.

1873. ‡MacLaren, Walter S. B. Newington House, Edinburgh.

1882. §Maclean, Inspector-General, C.B. 1 Rockstone-terrace, Southampton.

1876. ‡*M'Lean, Charles. 6 Claremont-terrace, Glasgow.*

1876. ‡*M'Lean, Mrs. Charles. 6 Claremont-terrace, Glasgow.*

1862. ‡Macleod, Henry Dunning. 17 Gloucester-terrace, Campden Hill-road, London, W.

1868. §M'Leod, Herbert, F.R.S., F.C.S. Indian Civil Engineering College, Cooper's Hill, Egham.

1875. ‡Macliver, D. 1 Broad-street, Bristol.

1875. ‡Macliver, P. S. 1 Broad-street, Bristol.

1861. *Maclure, John William, F.R.G.S., F.S.S. Whalley Range, Manchester.

1878. *M'Master, George, M.A., J.P. Donnybrook, Ireland.

1862. ‡Macmillan, Alexander. Streatham-lane, Upper Tooting, Surrey, S.W.

1874. ‡MacMordie, Hans, M.A. 8 Donegall-street, Belfast.

1871. ‡M'Nab, William Ramsay, M.D., Professor of Botany in the Royal College of Science, Dublin. 4 Vernon-parade, Clontarf, Dublin.

1870. ‡Macnaught, John, M.D. 74 Huskisson-street, Liverpool.

1867. ‡M'Neill, John. Balhousie House, Perth.

MacNeill, The Right Hon. Sir John, G.C.B., F.R.S.E., F.R.G.S., Granton House, Edinburgh.

1878. ‡Macnie, George. 59 Bolton-street, Dublin.

1852. *Macrory, Adam John. Duncairn, Belfast.

*Macrory, Edmund, M.A. 2 Ilchester-gardens, Prince's-square, London, W.

1876. *Mactear, James. 16 Burnbank-gardens, Glasgow.

1855. ‡Macvicar, Rev. John Gibson, D.D., LL.D. Moffat, N.B.

1868. ‡Magnay, F. A. Drayton, near Norwich.

1875. *Magnus, Philip. 48 Gloucester-place, Portman-square, London, W.

1879. ‡Mahomed, F. A. 13 St. Thomas-street, London, S.E.

1878. ‡Mahony, W. A. 34 College-green, Dublin.

1869. ‡Main, Robert. Admiralty, Whitehall, London, S.W.

*Malahide, The Right Hon. Lord Talbot de, M.A., D.C.L., F.R.S., F.G.S., F.S.A., M.R.I.A. Malahide Castle, Co. Dublin.

*Malcolm, Frederick. Morden College, Blackheath, London, S.E.

1881. ‡Malcolm, Lieut.-Colonel, R.E. 72 Nunthorpe-road, York.

1874. ‡Malcolmson, A. B. Friends' Institute, Belfast.

1863. ‡*Maling, C. T. Lovaine-crescent, Newcastle-on-Tyne.*

1857. ‡Mallet, John William, Ph.D., M.D., F.R.S., F.C.S., Professor of Chemistry in the University of Virginia, U.S.

1846. ‡Manby, Charles, F.R.S., F.G.S. 60 Westbourne-terrace, Hyde Park, London, W.

1870. ‡Manifold, W. H. 45 Rodney-street, Liverpool.

1866. §Mann, Robert James, M.D., F.R.A.S. 5 Kingsdown-villas, Wandsworth Common, S.W.

Manning, His Eminence Cardinal. Archbishop's House, Westminster, S.W.

1866. ‡Manning, John. Waverley-street, Nottingham.

Year of Election.

1878. §Manning, Robert. 4 Upper Ely-place, Dublin.
1864. ‡Mansel, J. C. Long Thorns, Blandford.
1870. ‡Marcoartu, Senor Don Arturo de. Madrid.
1864. ‡MARKHAM, CLEMENTS R., C.B., F.R.S., F.L.S., Sec.R.G.S., F.S.A. 21 Eccleston-square, Pimlico, London, S.W.
1863. ‡Marley, John. Mining Office, Darlington.
*Marling, Sir Samuel S., Bart., M.P. Stanley Park, Stroud, Gloucestershire.
1881. *Marr, John Edward, B.A., F.G.S. St. John's College, Cambridge.
1871. ‡MARRECO, A. FRIERE-. College of Physical Science, Newcastle-on-Tyne.
1857. ‡Marriott, William, F.C.S. Grafton-street, Huddersfield.
1842. Marsden, Richard. Norfolk-street, Manchester.
1870. ‡Marsh, John. Rann Lea, Rainhill, Liverpool.
1864. ‡Marsh, Thomas Edward Miller. 37 Grosvenor-place, Bath.
1882. *Marshall, A. Milnes, M.A., M.D., D.Sc., Professor of Zoology in Owens College, Manchester.
1881. ‡Marshall, D. H. Greenhill Cottage, Rothesay.
1881. *Marshall, John, F.R.A.S., F.G.S. Church Institute, Leeds.
1881. §Marshall, John Ingham Fearby. 28 St. Saviourgate, York.
1876. ‡Marshall, Peter. 6 Parkgrove-terrace, Glasgow.
1858. ‡Marshall, Reginald Dykes. Adel, near Leeds.
1849. *Marshall, William P. 15 Augustus-road, Birmingham.
1865. §MARTEN, EDWARD BINDON. Pedmore, near Stourbridge.
1848. ‡Martin, Henry D. 4 Imperial-circus, Cheltenham.
1878. ‡Martin, H. Newell. Christ's College, Cambridge.
1871. ‡Martin, Rev. Hugh, M.A. Greenhill Cottage, Lasswade, by Edinburgh.
1836. Martin, Studley. 177 Bedford-street South, Liverpool.
*Martindale, Nicholas. Queen's Park, Chester.
*Martineau, Rev. James, LL.D., D.D. 35 Gordon-square, London, W.C.
1865. ‡Martineau, R. F. Highfield-road, Edgbaston, Birmingham.
1865. ‡Martineau, Thomas. 7 Cannon-street, Birmingham.
1875. ‡Martyn, Samuel, M.D. 8 Buckingham-villas, Clifton, Bristol.
1878. ‡Masaki, Taiso. Japanese Consulate, 84 Bishopsgate-street Within, London, E.C.
1847. ‡MASKELYNE, NEVIL STORY, M.P., M.A., F.R.S., F.G.S., Professor of Mineralogy in the University of Oxford. 39 Cornwall-gardens, London, W.
1861. *Mason, Hugh. Groby Hall, Ashton-under-Lyne.
1879. ‡Mason, James, M.D. Montgomery House, Sheffield.
1868. ‡Mason, James Wood, F.G.S. The Indian Museum, Calcutta. (Care of Messrs. Henry S. King & Co., 65 Cornhill, London, E.C.)
1876. §Mason, Robert. 6 Albion-crescent, Dowanhill, Glasgow.
1876. ‡Mason, Stephen. 9 Rosslyn-terrace, Hillhead, Glasgow.
Massey, Hugh, Lord. Hermitage, Castleconnel, Co. Limerick.
1870. ‡*Massy, Frederick. 50 Grove-street, Liverpool.*
1865. *Mathews, G. S. 32 Augustus-road, Edgbaston, Birmingham.
1861. *MATHEWS, WILLIAM, M.A., F.G.S. 60 Harborne-road, Birmingham.
1881. §Mathwin, Henry, B.A. Bickerton House, Southport.
1865. ‡Matthews, C. E. Waterloo-street, Birmingham.
1858. ‡Matthews, F. C. Mandre Works, Driffield, Yorkshire.
1860. ‡Matthews, Rev. Richard Brown. Shalford Vicarage, near Guildford.

Year of Election.

1863. ‡Maughan, Rev. W. Benwell Parsonage, Newcastle-on-Tyne.
1865. *MAW, GEORGE, F.L.S., F.G.S., F.S.A. Benthall Hall, Broseley, Shropshire.
1876. ‡Maxton, John. 6 Belgrave-terrace, Glasgow.
1864. *Maxwell, Francis. Balgrove, North Berwick.
*Maxwell, Robert Perceval. Finnebrogue, Downpatrick.
1868. ‡Mayall, J. E., F.C.S. Stork's Nest, Lancing, Sussex.
1835. Mayne, Edward Ellis. Rocklands, Stillorgan, Ireland.
1878. *Mayne, Thomas. 33 Castle-street, Dublin.
1863. ‡Mease, George D. Bylton Villa, South Shields.
1881. ‡Meek, Sir James. Middlethorpe, York.
1871. ‡Meikie, James, F.S.S. 6 St. Andrew's-square, Edinburgh.
1879. §Meiklejohn, John W. S., M.D. H.M. Dockyard, Chatham.
1881. *MELDOLA, RAPHAEL, F.R.A.S., F.C.S., F.I.C. 21 John-street, Bedford-row, London, W.C.
1867. ‡MELDRUM, CHARLES, M.A., F.R.S., F.R.A.S. Port Louis, Mauritius.
1879. *Mellish, Henry. Hodsock Priory, Worksop.
1866. ‡MELLO, Rev. J. M., M.A., F.G.S. St. Thomas's Rectory, Brampton, Chesterfield.
1854. ‡Melly, Charles Pierre. 11 Rumford-street, Liverpool.
1881. ‡Melrose, James. Clifton, York.
1847. ‡Melville, Professor Alexander Gordon, M.D. Queen's College, Galway.
1863. ‡Melvin, Alexander. 42 Buccleuch-place, Edinburgh.
1877. *Menabrea, General Count. 35 Queen's-gate, London, S.W.
1862. ‡MENNELL, HENRY J. St. Dunstan's-buildings, Great Tower-street, London, E.C.
1879. ‡Merivale, John Herman, Professor of Mining in the College of Science, Newcastle-on-Tyne.
1879. ‡Merivale, Walter. Engineers' Office, North-Eastern Railway, Newcastle-on-Tyne.
1868. §MERRIFIELD, CHARLES W., F.R.S. 20 Girdler's-road, Brook Green, London, W.
1877. ‡Merrifield, John, Ph.D., F.R.A.S. Gascoigne-place, Plymouth.
1880. ‡Merry, Alfred S. Bryn Heulog, Sketty, near Swansea.
1872. *Messent, John. 429 Strand, London, W.C.
1863. ‡Messent, P. T. 4 Northumberland-terrace, Tynemouth.
1869. ‡MIALL, LOUIS C., F.G.S., Professor of Biology in Yorkshire College, Leeds.
1865. ‡Middlemore, William. Edgbaston, Birmingham.
1881. *Middlesbrough, The Right Rev. Richard Lacy, D.D., Bishop of. Middlesbrough.
1881. §Middleton, R. Morton, F.L.S. Hudworth Cottage, Castle Eden, Co. Durham.
1876. *Middleton, Robert T., M.P. 197 West George-street, Glasgow.
1866. ‡Midgley, John. Colne, Lancashire.
1867. ‡Midgley, Robert. Colne, Lancashire.
1881. §MILES, MORRIS. Barron Villa, Hill, Southampton.
1859. ‡Millar, John, J.P. Lisburn, Ireland.
1863. ‡Millar, John, M.D., F.L.S., F.G.S. Bethnal House, Cambridge-road, London, E.
Millar, Thomas, M.A., LL.D., F.R.S.E. Perth.
1876. ‡Millar, William. Highfield House, Dennistoun, Glasgow.
1876. ‡Millar, W. J. 145 Hill-street, Garnethill, Glasgow.
1882. §Miller, A. J. High-street, Southampton.
1876. ‡Miller, Daniel. 258 St. George's-road, Glasgow.

Year of
Election.

1875. ‡Miller, George. Brentry, near Bristol.
1861. *Miller, Robert. Poise House, Bosden, near Stockport.
1876. *Miller, Robert. 1 Lily Bank-terrace, Hillhead, Glasgow.
1876. ‡Miller, Thomas Paterson. Morriston House, Cambuslang, N.B.
1868. *Milligan, Joseph, F.L.S., F.G.S., F.R.A.S., F.R.G.S. 6 Craven-street, Strand, London, W.C.
1868. *MILLS, EDMUND J., D.Sc., F.R.S., F.C.S., Young Professor of Technical Chemistry in Anderson's College, Glasgow. 60 John-street, Glasgow.
*Mills, John Robert. 11 Bootham, York.
1880. ‡Mills, Mansfieldt H. Tapton-grove, Chesterfield.
Milne, Admiral Sir Alexander, Bart., G.C.B., F.R.S.E. 13 New-street, Spring-gardens, London, S.W.
1867. *MILNE-HOME, DAVID, M.A., F.R.S.E., F.G.S. 10 York-place, Edinburgh.
1882. *Milne, John, F.G.S., Professor of Geology in the Imperial College of Engineering, Tokio, Japan. 4 Bennett Park, Blackheath, London, S.E.
1882. §Milnes, Alfred, M.A., F.S.S. 30 Almeric-road, London, S.W.
1880. §Minchin, G. M., M.A. Royal Indian Engineering College, Cooper's Hill, Surrey.
1865. ‡Minton, Samuel, F.G.S. Oakham House, near Dudley.
1855. ‡Mirrlees, James Buchanan. 45 Scotland-street, Glasgow.
1859. ‡Mitchell, Alexander, M.D. Old Rain, Aberdeen.
1876. ‡Mitchell, Andrew. 20 Woodside-place, Glasgow.
1863. ‡Mitchell, C. Walker. Newcastle-on-Tyne.
1873. ‡Mitchell, Henry. Parkfield House, Bradford, Yorkshire.
1870. ‡Mitchell, John. Hall Foot, Clitheroe, Lancashire.
1868. ‡Mitchell, John, jun. Pole Park House, Dundee.
1862. **Mitchell, W. Stephen, M.A., LL.B. Caius College, Cambridge.*
1879. ‡MIVART, ST. GEORGE, M.D., F.R.S., F.L.S., F.Z.S., Professor of Biology in University College, Kensington. 71 Seymour-street, London, W.
1855. *Moffat, John, C.E. Ardrossan, Scotland.
1864. ‡Mogg, John Rees. High Littleton House, near Bristol.
1861. ‡MOLESWORTH, Rev. W. NASSAU, M.A. Spotland, Rochdale.
Mollan, John, M.D. 8 Fitzwilliam-square North, Dublin.
1878. §Molloy, Constantine. 70 Lower Gardiner-street, Dublin.
1877. *Molloy, Rev. Gerald, D.D. 86 Stephen's-green, Dublin.
1852. ‡*Molony, William, LL.D. Carrickfergus.*
1860. ‡Monk, Rev. William, M.A., F.R.A.S. Wymington Rectory, Higham Ferrers, Northamptonshire.
1853. ‡Monroe, Henry, M.D. 10 North-street, Sculcoates, Hull.
1882. *Montagu, Samuel. 96 Lancaster-gate, London, S.W.
1872. §Montgomery, R. Mortimer. 3 Porchester-place, Edgware-road, London, W.
1872. ‡Moon, W., LL.D. 104 Queen's-road, Brighton.
1881. §Moore, Henry. 4 Sheffield-terrace, Kensington, London, W.
Moore, John. 2 Meridian-place, Clifton, Bristol.
*MOORE, JOHN CARRICK, M.A., F.R.S., F.G.S. 113 Eaton-square, London, S.W.; and Corswall, Wigtonshire.
1866. *MOORE, THOMAS, F.L.S. Botanic Gardens, Chelsea, London, S.W.
1854. ‡MOORE, THOMAS JOHN, Cor. M.Z.S. Free Public Museum, Liverpool.
1877. ‡Moore, W. F. The Friary, Plymouth.
1857. *Moore, Rev. William Prior. The Royal School, Cavan, Ireland.

Year of Election.

1877. ‡Moore, William Vanderkemp. 15 Princess-square, Plymouth.
1871. ‡More, Alexander G., F.L.S., M.R.I.A. 3 Botanic View, Glasnevin, Dublin.
1881. §Morgan, Alfred. 97 Hartington-road, Sefton Park, Liverpool.
1873. ‡Morgan, Edward Delmar. 15 Rowland-gardens, London, W.
1882. §Morgan, Thomas. Cross House, Southampton.
1833. Morgan, William, D.C.L. Oxon. Uckfield, Sussex.
1878. ‡Morgan, William, Ph.D., F.C.S. Swansea.
1867. ‡Morison, William R. Dundee.
1863. †Morley, Samuel, M.P. 18 Wood-street, Cheapside, London, E.C.
1881. §Morrell, W. W. York City and County Bank, York.
1865. *Morrieson, Colonel Robert. Oriental Club, Hanover-square, London, W.
1880. ‡Morris, Alfred Arthur Vennor. Wernolau, Cross Inn R.S.O., Carmarthenshire.
*Morris, Rev. Francis Orpen, B.A. Nunburnholme Rectory, Hayton, York.
1880. ‡Morris, James. 6 Windsor-street, Uplands, Swansea.
1881. ‡Morris, John, M.A., F.G.S. Emeritus Professor of Geology in University College, London. 15 Upper Gloucester-place, London, N.W.
1880. ‡Morris, M. I. E. The Lodge, Penclawdd, near Swansea.
Morris, Samuel, M.R.D.S. Fortview, Clontarf, near Dublin.
1876. ‡Morris, Rev. S. S. O., M.A., R.N., F.C.S. H.M.S. 'Garnet,' S. Coast of America.
1874. ‡Morrison, G. J., C.E. 5 Victoria-street, Westminster, S.W.
1871. *Morrison, James Darsie. 27 Grange-road, Edinburgh.
1879. ‡*Morrison, Dr. R. Milner. 20 Pentland-terrace, Edinburgh.*
1865. §Mortimer, J. R. St. John's-villas, Driffield.
1869. †Mortimer, William. Bedford-circus, Exeter.
1857. §Morton, George H., F.G.S. 122 London-road, Liverpool.
1858. *Morton, Henry Joseph. 2 Westbourne-villas, Scarborough.
1871. ‡Morton, Hugh. Belvedere House, Trinity, Edinburgh.
1857. ‡Moses, Marcus. 4 Westmoreland-street, Dublin.
1868. ‡Moseley, H. N., M.A., F.R.S., Linacre Professor of Human and Comparative Anatomy in the University of Oxford. 14 St. Giles', Oxford.
Mosley, Sir Oswald, Bart., D.C.L. Rolleston Hall, Burton-upon-Trent, Staffordshire.
Moss, John. Otterspool, near Liverpool.
1878. *Moss, John Francis. Ranmoor, Sheffield.
1870. ‡Moss, John Miles, M.A. 2 Esplanade, Waterloo, Liverpool.
1876. §Moss, Richard Jackson, F.C.S., M.R.I.A. 66 Kenilworth-square, Rathgar, Dublin.
1873. *Mosse, George Staley. 2 Albany-villas, Queen's-road, Twickenham.
1874. *Mosse, J. R. Conservative Club, London, S.W.
1873. †Mossman, William. Woodhall, Calverley, Leeds.
1869. §Mott, Albert J., F.G.S. Crickley Hill, Gloucester.
1865. ‡Mott, Charles Grey. The Park, Birkenhead.
1866. §Mott, Frederick T., F.R.G.S. Birstall Hill, Leicester.
1862. *Mouat, Frederick John, M.D., Local Government Inspector. 12 Durham-villas, Campden Hill, London, W.
1856. ‡Mould, Rev. J. G., B.D. Fulmodeston Rectory, Dereham, Norfolk.
1878. *Moulton, J. Fletcher, M.A., F.R.S. 74 Onslow-gardens, London, S.W.

Year of Election.

1863. ‡Mounsey, Edward. Sunderland.
Mounsey, John. Sunderland.
1861. *Mountcastle, William Robert. Bridge Farm, Ellenbrook, near Manchester.
1877. ‡MOUNT-EDGCUMBE, The Right Hon. the Earl of, D.C.L. Mount-Edgcumbe, Devonport.
1882. §MOUNT-TEMPLE, The Right Hon. Lord. Broadlands, Romsey, Hants.
Mowbray, James. Combus, Clackmannan, Scotland.
1850. ‡Mowbray, John T. 15 Albany-street, Edinburgh.
1876. *Muir, John. 6 Park-gardens, Glasgow.
1874. ‡Muir, M. M. Pattison, F.R.S.E. Owens College, Manchester.
1876. §Muir, Thomas. High School, Glasgow.
1872. ‡Muirhead, Alexander, D.Sc., F.C.S. 29 Regency-street, Westminster, S.W.
1871. *MUIRHEAD, HENRY, M.D. Bushy Hill, Cambuslang, Lanarkshire.
1876. *Muirhead, Robert Franklin, B.Sc. Meikle Cloak, Lochwinnoch, Renfrewshire.
Munby, Arthur Joseph. 6 Fig-tree-court, Temple, London, E.C.
1880. §Muller, Hugo M. 1 Grunangergasse, Vienna.
1866. ‡MUNDELLA, The Right Hon. A. J., M.P., F.R.S., F.R.G.S. The Park, Nottingham.
1876. ‡Munro, Donald, F.C.S. The University, Glasgow.
1872. *Munster, H. Sillwood Lodge, Brighton.
1864. ‡MURCH, JEROM. Cranwells, Bath.
*_Murchison, John Henry. Surbiton Hill, Kingston._
1864. *Murchison, K. R. Brockhurst, East Grinstead.
1876. ‡_Murdoch, James. Altony Albany, Girvan, N.B._
1855. ‡Murdoch, James B. Hamilton-place, Langside, Glasgow.
1852. ‡Murney, Henry, M.D. 10 Chichester-street, Belfast.
1852. ‡Murphy, Joseph John. Old Forge, Dunmurry, Co. Antrim.
1869. ‡Murray, Adam. 4 Westbourne-crescent, Hyde Park, London, W.
Murray, John, F.G.S., F.R.G.S. 50 Albemarle-street, London, W.; and Newsted, Wimbledon, Surrey.
1871. ‡Murray, John. 3 Clarendon-crescent, Edinburgh.
1859. ‡Murray, John, M.D. Forres, Scotland.
*Murray, John, C.E. Downlands, Sutton, Surrey.
‡Murray, Rev. John. Morton, near Thornhill, Dumfriesshire.
1872. ‡Murray, J. Jardine. 99 Montpellier-road, Brighton.
1863. ‡Murray, William. 34 Clayton-street, Newcastle-on-Tyne.
1859. *Murton, James. Highfield, Silverdale, Carnforth.
1874. §Musgrave, James, J.P. Drumglass House, Belfast.
1861. ‡Musgrove, John, jun. Bolton.
1870. *Muspratt, Edward Knowles. Seaforth Hall, near Liverpool.
1859. §MYLNE, ROBERT WILLIAM, F.R.S., F.G.S., F.S.A. 2 Middle Scotland-yard, London, S.W.

1842. Nadin, Joseph. Manchester.
1876. §Napier, James S. 9 Woodside-place, Glasgow.
1876. ‡Napier, John. Saughfield House, Hillhead, Glasgow.
*Napier, Captain Johnstone, C.E. Laverstock House, Salisbury.
1872. ‡Nares, Captain Sir G. S., K.C.B., R.N., F.R.S., F.R.G.S. 23 St. Philip's-road, Surbiton.
1866. ‡_Nash, Davyd W., F.S.A., F.L.S. 10 Imperial-square, Cheltenham._

Year of Election.

1850. *Nasmyth, James. Penshurst, Tunbridge.
1864. ‡Natal, The Right Rev. John William Colenso, D.D., Lord Bishop of. Natal.
1873. ‡Neill, Alexander Renton. Fieldhead House, Bradford, Yorkshire.
1873. ‡Neill, Archibald. Fieldhead House, Bradford, Yorkshire.
1855. ‡Neilson, Walter. 172 West George-street, Glasgow.
1865. ‡*Neilson, W. Montgomerie. Glasgow.*
1876. ‡Nelson, D. M. 48 Gordon-street, Glasgow.
1868. ‡Nevill, Rev. H. R. The Close, Norwich.
1866. *Nevill, The Right Rev. Samuel Tarratt, D.D., F.L.S., Bishop of Dunedin, New Zealand.
1857. ‡Neville, John, C.E., M.R.I.A. Roden-place, Dundalk, Ireland.
1852. ‡Neville, Parke, C.E., M.R.I.A. 58 Pembroke-road, Dublin.
1869. ‡Nevins, John Birkbeck, M.D. 3 Abercromby-square, Liverpool.
1842. New, Herbert. Evesham, Worcestershire.
Newall, Henry. Hare Hill, Littleborough, Lancashire.
*Newall, Robert Stirling, F.R.S., F.R.A.S. Ferndene, Gateshead-upon-Tyne.
1879. ‡Newbould, John. Sharrow Bank, Sheffield.
1866. *Newdigate, Albert L. 25 Craven-street, Charing Cross, London, W.C.
1876. ‡Newhaus, Albert. 1 Prince's-terrace, Glasgow.
1842. *Newman, Professor Francis William. 15 Arundel-crescent, Weston-super-Mare.
1860. *Newton, Alfred, M.A., F.R.S., F.L.S., Professor of Zoology and Comparative Anatomy in the University of Cambridge. Magdalen College, Cambridge.
1872. ‡Newton, Rev. J. 125 Eastern-road, Brighton.
1865. †Newton, Thomas Henry Goodwin. Clopton House, near Stratford-on-Avon.
1882. §Nias, J. B., B.A. 56 Montagu-square, London, W.
1867. ‡Nicholl, Thomas. Dundee.
1875. ‡Nicholls, J. F. City Library, Bristol.
1866. ‡Nicholson, Sir Charles, Bart., M.D., D.C.L., LL.D., F.G.S., F.R.G.S. The Grange, Totteridge, Herts.
1838. *Nicholson, Cornelius, F.G.S., F.S.A. Ashleigh, Ventnor, Isle of Wight.
1861. *Nicholson, Edward. 88 Mosley-street, Manchester.
1871. §Nicholson, E. Chambers. Herne Hill, London, S.E.
1867. ‡Nicholson, Henry Alleyne, M.D., D.Sc., F.G.S., Professor of Natural History in the University of Aberdeen.
1881. §Nicholson, William R. Clifton, York.
1867. ‡Nimmo, Dr. Matthew. Nethergate, Dundee.
1878. ‡Niven, Charles, M.A., F.R.S., F.R.A.S., Professor of Natural Philosophy in the University of Aberdeen. Aberdeen.
1877. ‡Niven, James, M.A. King's College, Aberdeen.
‡Nixon, Randal C. J., M.A. Green Island, Belfast.
1863. *Noble, Captain Andrew, F.R.S., F.R.A.S., F.C.S. Elswick Works, Newcastle-on-Tyne.
1880. ‡Noble, John. Rossenstein, Thornhill-road, Croydon, Surrey.
1879. ‡Noble, T. S., F.G.S. Lendal, York.
1870. ‡Nolan, Joseph, M.R.I.A. 14 Hume-street, Dublin.
1882. §Norfolk, F. Fitzhugh's Park, Southampton.
1859. ‡Norfolk, Richard. Ladygate, Beverley.
1868. Norgate, William. Newmarket-road, Norwich.
1863. §Norman, Rev. Alfred Merle, M.A. Burnmoor Rectory, Fence House, Co. Durham.

Year of Election.

Norreys, Sir Denham Jephson, Bart. Mallow Castle, Co. Cork.
1865. ‡NORRIS RICHARD, M.D. 2 Walsall-road, Birchfield, Birmingham.
1872. ‡Norris, Thomas George. Corphwysfa, Llanrwst, North Wales.
1881. §North, Samuel William, M.R.C.S., F.G.S. 84 Micklegate, York.
1881. ‡North, William, B.A., F.C.S. 34 Bernard-street, Russell-square, London, W.C.
1869. ‡NORTHCOTE, The Right Hon. Sir STAFFORD H., Bart., K.G.C.B., M.P., F.R.S. Pynes, Exeter.
*NORTHWICK, The Right Hon. Lord, M.A. 7 Park-street, Grosvenor-square, London, W.
NORTON, The Right Hon. Lord, K.C.M.G. 35 Eaton-place, London, S.W.; and Hamshall, Birmingham.
1868. ‡Norwich, The Hon. and Right Rev. J. T. Pelham, D.D., Lord Bishop of. Norwich.
1861. ‡Noton, Thomas. Priory House, Oldham.
Nowell, John. Farnley Wood, near Huddersfield.
1878. ‡Nugent, Edward, C.E. Seel's-buildings, Liverpool.

1882. §Obach, Eugene, Ph.D. 17 Charlton-villas, Old Charlton, Kent.
1878. ‡O'Brien, Murrough. 1 Willow-terrace, Blackrock, Co. Dublin.
O'Callaghan, George. Tallas, Co. Clare.
1878. ‡O'Carroll, Joseph F. 78 Rathgar-road, Dublin.
1878. ‡O'Conor Don, The, M.P. Clonalis, Castlerea, Ireland.
Odgers, Rev. William James. Savile House, Fitzjohn's-avenue, Hampstead, London, N.W.
1858. *ODLING, WILLIAM, M.B., F.R.S., F.C.S., Waynflete Professor of Chemistry in the University of Oxford. 15 Norham-gardens, Oxford.
1857. ‡O'Donnavan, William John. 54 Kenilworth-square, Rathgar, Dublin.
1877. §Ogden, Joseph. 46 London-wall, London, E.C.
1876. ‡Ogilvie, Campbell P. Sizewell House, Lenton, Suffolk.
1859. ‡Ogilvie, Rev. C. W. Norman. Baldovan House, Dundee.
1874. §Ogilvie, Thomas Robertson. Bank Top, 3 Lyle-street, Greenock, N.B.
*OGILVIE-FORBES, GEORGE, M.D., Professor of the Institutes of Medicine in Marischal College, Aberdeen. Boyndlie, Fraserburgh, N.B.
1863. ‡OGILVY, Sir JOHN, Bart. Inverquharity, N.B.
*Ogle, William, M.D., M.A. The Elms, Derby.
1859. ‡Ogston, Francis, M.D. 18 Adelphi-court, Aberdeen.
1837. ‡O'Hagan, John, M.A., Q.C. 22 Upper Fitzwilliam-street, Dublin.
1874. ‡O'HAGAN, The Right Hon. Lord, M.R.I.A. 34 Rutland-square West, Dublin.
1862. ‡O'KELLY, JOSEPH, M.A., M.R.I.A. 14 Hume-street, Dublin.
1881. ‡Oldfield, Joseph. Lendal, York.
1853. §OLDHAM, JAMES, C.E. Cottingham, near Hull.
1863. ‡Oliver, Daniel, F.R.S., Professor of Botany in University College, London. Royal Gardens, Kew, Surrey.
§Olsen, O. T., F.R.A S., F.R.G.S. 3 St. Andrew's-terrace, Grimsby.
*OMMANNEY, Admiral Sir ERASMUS, C.B., F.R.S., F.R.A.S., F.R.G.S. The Towers, Yarmouth, Isle of Wight.
1880. *Ommanney, Commander E. A., R.N., 44 Charing Cross, London, W.
1872. ‡Onslow, D. Robert. New University Club, St. James's, London, S.W.
1867. ‡Orchar, James G. 9 William-street, Forebank, Dundee.

Year of
Election.

1880. ‡O'Reilly, J. P., C.E., Professor of Mining and Mineralogy in the Royal College of Science, Dublin.
1842. ORMEROD, GEORGE WAREING, M.A., F.G.S. Woodway, Teignmouth.
1861. ‡Ormerod, Henry Mere. Clarence-street, Manchester; and 11 Woodland-terrace, Cheetham Hill, Manchester.
1858. ‡Ormerod, T. T. Brighouse, near Halifax.
1835. ORPEN, JOHN H., LL.D., M.R.I.A. 58 Stephen's-green, Dublin.
1838. Orr, Alexander Smith. 57 Upper Sackville-street, Dublin.
1873. ‡Osborn, George. 47 Kingscross-street, Halifax.
1865. ‡Osborne, E. C. Carpenter-road, Edgbaston, Birmingham.
*OSLER, A. FOLLETT, F.R.S. South Bank, Edgbaston, Birmingham.
1877. *Osler, Miss A. F. South Bank, Edgbaston, Birmingham.
1865. *Osler, Henry F. 50 Carpenter-road, Edgbaston, Birmingham.
1869. *Osler, Sidney F. 1 Pownall-gardens, Hounslow, near London.
1882. *Oswald, T. R. New Place House, Southampton.
1881. *Ottewell, Alfred D. 83 Siddals-road, Derby.
1854. ‡Outram, Thomas. Greetland, near Halifax.
OVERSTONE, SAMUEL JONES LLOYD, Lord, F.G.S. 2 Carlton-gardens, London, S.W.; and Wickham Park, Bromley.
1882. §Owen, Rev. C. M., M.A. Woolston Vicarage, Southampton.
1870. ‡Owen, Harold. The Brook Villa, Liverpool.
1857. ‡Owen, James H. Park House, Sandymount, Co. Dublin.
OWEN, RICHARD, C.B., M.D., D.C.L., LL.D., F.R.S., F.L.S., F.G.S., Hon. M.R.S.E., Director of the Natural-History Department, British Museum. Sheen Lodge, Mortlake, Surrey, S.W.
1877. ‡Oxland, Dr. Robert, F.C.S. 8 Portland-square, Plymouth.

1872. *Paget, Joseph. Stuffynwood Hall, Mansfield, Nottingham.
1875. ‡Paine, William Henry, M.D., F.G.S. Stroud, Gloucestershire.
1870. *Palgrave, R. H. Inglis, F.R.S., F.S.S. 11 Britannia-terrace, Great Yarmouth.
1873. ‡Palmer, George, M.P. The Acacias, Reading, Berks.
1866. §Palmer, H. 76 Goldsmith-street, Nottingham.
1878. *Palmer, Joseph Edward. Lyons Mills, Straffan Station, Dublin.
1866. §Palmer, William. Iron Foundry, Canal-street, Nottingham.
1872. **Palmer, W. R. Hawthorne, Rivercourt-road, Hammersmith, W.*
Palmes, Rev. William Lindsay, M.A. Naburn Hall, York.
1880. *Parke, George Henry, F.L.S., F.G.S. Barrow-in-Furness, Lancashire.
1857. *Parker, Alexander, M.R.I.A. 59 William-street, Dublin.
1863. ‡Parker, Henry. Low Elswick, Newcastle-on-Tyne.
1863. ‡Parker, Rev. Henry. Idlerton Rectory, Low Elswick, Newcastle-on-Tyne.
1874. ‡Parker, Henry R., LL.D. Methodist College, Belfast.
Parker, Richard. Dunscombe, Cork.
1865. *Parker, Walter Mantel. High-street, Alton, Hants.
Parker, Rev. William. Saham, Norfolk.
1853. ‡Parker, William. Thornton-le-Moor, Lincolnshire.
1865. *Parkes, Samuel Hickling, F.L.S. 6 St. Mary's-row, Birmingham.
1864. ‡PARKES, WILLIAM. 23 Abingdon-street, Westminster, S.W.
1879. §Parkin, William, F.S.S. The Mount, Sheffield.
1859. ‡Parkinson, Robert, Ph.D. West View, Toller-lane, Bradford, Yorkshire.
1841. Parnell, Edward A., F.C.S. Ashley Villa, Swansea.
1862. *Parnell, John, M.A. 1 The Common, Upper Clapton, London, E.
Parnell, Richard, M.D., F.R.S.E. Gattonside Villa, Melrose, N.B.

Year of Election.

1877. ‡Parson, T. Edgcumbe. 36 Torrington-place, Plymouth.
1865. *Parsons, Charles Thomas. Norfolk-road, Edgbaston, Birmingham.
1878. ‡Parsons, Hon. C. A. 10 Connaught-place, London, W.
1878. ‡Parsons, Hon. and Rev. R. C. 10 Connaught-place, London, W.
1875. ‡Pass, Alfred C. Rushmere House, Durdham Down, Bristol.
1881. §Patchitt, Edward Cheshire. 128 Derby-road, Nottingham.
1861. ‡Patterson, Andrew. Deaf and Dumb School, Old Trafford, Manchester.
1871. *Patterson, A. Henry. 3 New-square, Lincoln's Inn, London, W.C.
1863. ‡Patterson, H. L. Scott's House, near Newcastle-on-Tyne.
1867. ‡Patterson, James. Kinnettles, Dundee.
1876. §Patterson, T. L. Belmont, Margaret-street, Greenock.
1874. ‡Patterson, W. H., M.R.I.A. 26 High-street, Belfast.
1863. ‡Pattinson, John, F.C.S. 75 The Side, Newcastle-on-Tyne.
1863. ‡Pattinson, William. Felling, near Newcastle-upon-Tyne.
1867. §Pattison, Samuel Rowles, F.G.S. 50 Lombard-street, London, E.C.
1864. ‡Pattison, Dr. T. H. London-street, Edinburgh.
1879. *Patzer, F. R. Stoke-on-Trent.
1863. ‡PAUL, BENJAMIN H., Ph.D. 1 Victoria-street, Westminster, S.W.
1863. ‡PAVY, FREDERICK WILLIAM, M.D., F.R.S., Lecturer on Physiology and Comparative Anatomy and Zoology at Guy's Hospital. 35 Grosvenor-street, London, W.
1864. ‡Payne, Edward Turner. 3 Sydney-place, Bath.
1881. ‡Payne, J. Buxton. 15 Mosley-street, Newcastle-on-Tyne.
1877. ‡Payne, J. C. Charles. 5 Princess-gardens, The Plains, Belfast.
1881. §Payne, Mrs. 5 Princess-gardens, The Plains, Belfast.
1866. ‡Payne, Dr. Joseph F. 78 Wimpole-street, London, W.
1876. ‡Peace, G. H. Morton Grange, Eccles, near Manchester.
1879. ‡Peace, William K. Western Bank, Sheffield.
1847. ‡PEACH, CHARLES W., Pres. R.P.S. Edin., A.L.S. 30 Haddington-place, Leith-walk, Edinburgh.
1875. ‡Peacock, Thomas Francis. 12 South-square, Gray's Inn, London, W.C.
1881. *PEARCE, HORACE, F.L.S., F.G.S. The Limes, Stourbridge.
1882. §Pearce, Walter, B.Sc., F.C.S. St. Mary's Hospital, Paddington, London, W.
1876. ‡Pearce, W. Elmpark House, Govan, Glasgow.
*Pearsall, Thomas John, F.C.S. Birkbeck Literary and Scientific Institution, Southampton-buildings, Chancery-lane, London, W.C.
1881. §Pearse, Richard Seward. Southampton.
1881. ‡Pearson, John. Glentworth House, The Mount, York.
1872. *Pearson, Joseph. Lern Side Works, Nottingham.
1881. ‡Pearson, Richard. 23 Bootham, York.
1870. ‡Pearson, Rev. Samuel. 48 Prince's-road, Liverpool.
1863. §Pease, H. F. Brinkburn, Darlington.
1863. ‡Pease, Sir Joseph W., Bart., M.P. Hutton Hall, near Guisborough.
1863. ‡Pease, J. W. Newcastle-on-Tyne.
1858. *Pease, Thomas, F.G.S. Cote Bank, Westbury-on-Trym, near Bristol.
Peckitt, Henry. Carlton Husthwaite, Thirsk, Yorkshire.
1855. *Peckover, Alexander, F.L.S., F.R.G.S. Harecroft House, Wisbech, Cambridgeshire.
*Peckover, Algernon, F.L.S. Sibald's Holme, Wisbech, Cambridgeshire.
1878. *Peek, William. St. Clair, Hayward's Heath, Sussex.

Year of Election.

*Peel, George. Soho Iron Works, Manchester.
1873. ‡Peel, Thomas. 9 Hampton-place, Bradford, Yorkshire.
1881. §Peggs, J. Wallace. 21 Queen Anne's-gate, London, S.W.
1861. *Peile, George, jun. Shotley Bridge, Co. Durham.
1861. *Peiser, John. Barnfield House, 491 Oxford-street, Manchester.
1878. ‡Pemberton, Charles Seaton. 44 Lincoln's Inn-fields, London, W.C.
1865. ‡Pemberton, Oliver. 18 Temple-row, Birmingham.
1861. *Pender, John, M.P. 18 Arlington-street, London, S.W.
1868. ‡Pendergast, Thomas. Lancefield, Cheltenham.
1856. §PENGELLY, WILLIAM, F.R.S., F.G.S. Lamorna, Torquay.
1881. ‡Penty, W. G. Melbourne-street, York.
1875. ‡Percival, Rev. J., M.A., LL.D., President of Trinity College, Oxford.
1845. ‡PERCY, JOHN, M.D., F.R.S., F.G.S., 1 Gloucester-crescent, Hyde Park, London, W.
*Perigal, Frederick. Thatched House Club, St. James's-street, London, S.W.
1868. *PERKIN, WILLIAM HENRY, F.R.S, F.C.S. The Chestnuts, Sudbury, Harrow.
1877. §Perkins, Loftus. 140 Abbey-road, Kilburn, London, N.W.
Perkins, Rev. R. B., D.C.L. Wotton-under-Edge, Gloucestershire.
1864. *Perkins, V. R. 54 Gloucester-street, London, S.W.
Perry, The Right Rev. Charles, M.A., D.D. 32 Avenue-road, Regent's Park, London, N.W.
1879. ‡Perry, James. Roscommon.
1874. *PERRY, JOHN. 14 Talgarth-road, West Kensington, London, S.W.
1883. §Perry, Ottley L., F.R.G.S. Bolton-le-Moors, Lancashire.
1870. *PERRY, Rev. S. J., F.R.S., F.R.A.S., F.M.S. Stonyhurst College Observatory, Whalley, Blackburn.
1861. *Petrie, John. South-street, Rochdale.
Peyton, Abel. Oakhurst, Edgbaston, Birmingham.
1871. *Peyton, John E. H., F.R.A.S., F.G.S. 1 Uplands, St. Leonard's-on-Sea.
1882. §Pfoundes, Charles, F.R.G.S. Spring Gardens, London, S.W.
1867. ‡PHAYRE, Lieut.-General Sir ARTHUR, K.C.S.I., C.B. Athenæum Club, Pall Mall, London, S.W.
1863. *PHENÉ, JOHN SAMUEL, LL.D., F.S.A., F.G.S., F.R.G.S. 5 Carlton-terrace, Oakley-street, London, S.W.
1870. ‡Philip, T. D. 51 South Castle-street, Liverpool.
1853. *Philips, Rev. Edward. Hollington, Uttoxeter, Staffordshire.
1853. *Philips, Herbert. 35 Church-street, Manchester.
Philips, Robert N. The Park, Manchester.
1877. §Philips, T. Wishart. 33 Woodstock-road, Poplar, London, E.
1863. ‡Philipson, Dr. 1 Savile-row, Newcastle-on-Tyne.
1862. ‡Phillips, Rev. George, D.D. Queen's College, Cambridge.
1872. ‡PHILLIPS, J. ARTHUR, F.R.S., F.G.S., F.C.S. 18 Fopstone-road, Earl's Court-road, London, S.W.
1880. §Phillips, John H., Hon. Sec. Philosophical and Archæological Society, Scarborough.
1881. ‡Phillips, William. 9 Bootham-terrace, York.
1868. ‡Phipson, R. M., F.S.A. Surrey-street, Norwich.
1868. ‡PHIPSON, T. L., Ph.D., F.C.S. 4 The Cedars, Putney, Surrey, S.W.
1864. ‡Pickering, William. Oak View, Clevedon.
1870. ‡Picton, J. Allanson, F.S.A. Sandyknowe, Wavertree, Liverpool.
1870. ‡*Pigot, Rev. E. V. Malpas, Cheshire.*
1871. ‡Pigot, Thomas F., C.E., M.R.I.A. Royal College of Science, Dublin.
*Pike, Ebenezer. Besborough, Cork.

Year of Election.

1865. ‡PIKE, L. OWEN. 201 Maida-vale, London, W.
1873. ‡Pike, W. H. 4 The Grove, Highgate, London, N.
1857. ‡Pilkington, Henry M., M.A., Q.C. 45 Upper Mount-street, Dublin.
1863. *PIM, Captain BEDFORD C. T., R.N., F.R.G.S. Leaside, Kingswood-road, Upper Norwood, London, S.E.
Pim, George, M.R.I.A. Brenanstown, Cabinteely, Co. Dublin.
Pim, Jonathan. Harold's Cross, Dublin.
1877. ‡Pim, Joseph T. Greenbank, Monkstown, Co. Dublin.
1868. ‡Pinder, T. R. St. Andrew's, Norwich.
1876. ‡Pirie, Rev. G. Queen's College, Cambridge.
1859. ‡Pirrie, William, M.D., LL.D. 238 Union-street West, Aberdeen.
1866. ‡Pitcairn, David. Dudhope House, Dundee.
1875. ‡Pitman, John. Redcliff Hill, Bristol.
1864. ‡Pitt, R. 5 Widcomb-terrace, Bath.
1868. ‡PITT-RIVERS, Major-General A. H. L., F.R.S., F.G.S., F.R.G.S., F.S.A. 4 Grosvenor-gardens, London, S.W.
1872. ‡Plant, Mrs. H. W. 28 Evington-street, Leicester.
1869. §PLANT, JAMES, F.G.S. 40 West-terrace, West-street, Leicester.
1865. ‡Plant, Thomas L. Camp Hill, and 33 Union-street, Birmingham.
1842. PLAYFAIR, The Right Hon. LYON, C.B., Ph.D., LL.D., M.P., F.R.S. L. & E., F.C.S. 68 Onslow-gardens, South Kensington, London, S.W.
1867. ‡PLAYFAIR, Lieut.-Colonel R. L., H.M. Consul, Algeria. (Messrs. King & Co., Pall Mall, London, S.W.)
1857. ‡Plunkett, Thomas. Ballybrophy House, Borris-in-Ossory, Ireland.
1861. *POCHIN, HENRY DAVIS, F.C.S. Bodnant Hall, near Conway.
1881. §Pocklington, Henry. 20 Park-row, Leeds.
1846. ‡POLE, WILLIAM, Mus. Doc., F.R.S., M.I.C.E. Athenæum Club, Pall Mall, London, S.W.
*Pollexfen, Rev. John Hutton, M.A. Middleton Tyas Vicarage, Richmond, Yorkshire.
Pollock, A. 52 Upper Sackville-street, Dublin.
1862. *Polwhele, Thomas Roxburgh, M.A., F.G.S. Polwhele, Truro, Cornwall.
1854. ‡Poole, Braithwaite. Birkenhead.
1868. ‡Portal, Wyndham S. Malshanger, Basingstoke.
1874. ‡Porter, Rev. J. Leslie, D.D., LL.D., President of Queen's College, Belfast.
1866. §Porter, Robert. Montpelier Cottage, Beeston, Nottingham.
1863. ‡Potter, D. M. Cramlington, near Newcastle-on-Tyne.
*POTTER, EDMUND, F.R.S. Camfield-place, Hatfield, Herts.
1857. *POUNDEN, Captain LONSDALE, F.R.G.S. Junior United Service Club, St. James's-square, London, S.W.; and Brownswood House, Enniscorthy, Co. Wexford.
1873. *Powell, Francis S. Horton Old Hall, Yorkshire; and 1 Cambridge-square, London, W.
1881. §Powell, George Baden, M.A., F.R.A.S., F.S.S. 8 St. George's-place, Hyde Park Corner, London, S.W.
1875. ‡Powell, William Augustus Frederick. Norland House, Clifton, Bristol.
1867. ‡Powrie, James. Reswallie, Forfar.
1855. *Poynter, John E. Clyde Neuk, Uddingston, Scotland.
1869. *PREECE, WILLIAM HENRY, F.R.S. Gothic Lodge, Wimbledon Common, Surrey.
Prest, The Venerable Archdeacon Edward. The College, Durham.
1881. §Preston, Rev. Thomas Arthur, M.A. The Green, Marlborough.

Year of Election.

*PRESTWICH, JOSEPH, M.A., F.R.S., F.G.S., F.C.S., Professor of Geology in the University of Oxford. 35 St. Giles', Oxford; and Shoreham, near Sevenoaks.

1871. ‡Price, Astley Paston. 47 Lincoln's-Inn-Fields, London, W.C.

1856. *PRICE, Rev. BARTHOLOMEW, M.A., F.R.S., F.R.A.S., Sedleian Professor of Natural Philosophy in the University of Oxford, 11 St. Giles's, Oxford.

1872. ‡Price, David S., Ph.D. 26 Great George-street, Westminster, S.W.

1882. §Price, John E., F.S.A. 60 Albion-road, Stoke Newington, London, N.

Price, J. T. Neath Abbey, Glamorganshire.

1881. §Price, Peter. Crockherbtown, Cardiff.

1875. *Price, Rees. 1 Montague-place, Glasgow.

1870. *Price, Major W. E., F.G.S. Hillfield, Gloucester.

1875. *Price, William Philip. Tibberton Court, Gloucester.

1876. ‡Priestley, John. 174 Lloyd-street, Greenheys, Manchester.

1875. ‡Prince, Thomas. 6 Marlborough-road, Bradford, Yorkshire.

1864. *Prior, R. C. A., M.D. 48 York-terrace, Regent's Park, London, N.W.

1846. *PRITCHARD, Rev. CHARLES, M.A., F.R.S., F.G.S., F.R.A.S., Professor of Astronomy in the University of Oxford. 8 Keble-terrace, Oxford.

1876. *PRITCHARD, URBAN, M.D., F.R.C.S. 3 George-street, Hanover-square, London, W.

1872. ‡Pritchard, Rev. W. Gee. Brignal Rectory, Barnard Castle, Co. Durham.

1881. §Procter, John William. 23 St. Paul's-square, York.

1863. ‡Proctor, R. S. Summerhill-terrace, Newcastle-on-Tyne.

Proctor, Thomas. Elmsdale House, Clifton Down, Bristol.

Proctor, William. Elmhurst, Higher Erith-road, Torquay.

1863. *Prosser, Thomas. 25 Harrison-place, Newcastle-on-Tyne.

1863. ‡Proud, Joseph. South Hetton, Newcastle-on-Tyne.

1879. *Prouse, Oswald Milton, F.G.S., F.R.G.S. 4 Cambridge-villas, Richmond Park-road, Kingston-on-Thames.

1865. ‡Prowse, Albert P. Whitchurch Villa, Mannamead, Plymouth.

1872. *Pryor, M. Robert. Weston Manor, Stevenage, Herts.

1871. *Puckle, Thomas John. Woodcote-grove, Carshalton, Surrey.

1873. ‡Pullan, Lawrence. Bridge of Allan, N.B.

1867. *Pullar, Robert. Tayside, Perth.

1842. *Pumphrey, Charles. Southfield, King's Norton, near Birmingham.

Punnet, Rev. John, M.A., F.C.P.S. St. Earth, Cornwall.

1852. ‡Purdon, Thomas Henry, M.D. Belfast.

1860. ‡PURDY, FREDERICK, F.S.S., Principal of the Statistical Department of the Poor Law Board, Whitehall, London. Victoria-road, Kensington, London, W.

1881. ‡Purey-Cust, Very Rev. Arthur Percival, M.A., Dean of York. The Deanery, York.

1882. §Purrott, Charles. West End, near Southampton.

1874. ‡PURSER, FREDERICK, M.A. Rathmines, Dublin.

1866. ‡PURSER, Professor JOHN, M.A., M.R.I.A. Queen's College, Belfast.

1878. ‡Purser, John Mallet. 3 Wilton-terrace, Dublin.

1860. *Pusey, S. E. B. Bouverie. Pusey House, Faringdon.

1868. §PYE-SMITH, P. H., M.D. 54 Harley-street, W.; and Guy's Hospital, London, S.E.

1879. §Pye-Smith, R. J. 7 Surrey-street, Sheffield.

1861. *Pyne, Joseph John. The Willows, Albert-road, Southport.

1870. ‡Rabbits, W. T. Forest Hill, London, S.E.

1860. ‡RADCLIFFE, CHARLES BLAND, M.D. 25 Cavendish-square, London, W.

Year of Election.

1870. ‡Radcliffe, D. R. Phœnix Safe Works, Windsor, Liverpool.
1877. ‡Radford, George D. Mannamead, Plymouth.
1879. ‡Radford, R. Heber, M.I.C.E. Wood Bank, Pitsmoor, Sheffield.
*Radford, William, M.D. Sidmount, Sidmouth.
1855. *Radstock, Lord. 70 Portland-place, London, W.
1878. ‡Rae, John, M.D., LL.D., F.R.S. 2 Addison-gardens South, Kensington, London, W.
1854. ‡Raffles, Thomas Stamford. 13 Abercromby-square, Liverpool.
1864. ‡Rainey, James T. St. George's Lodge, Bath.
Rake, Joseph. Charlotte-street, Bristol.
1863. ‡RAMSAY, ALEXANDER, F.G.S. 2 Cowper-road, Acton, Middlesex, W.
1845. ‡RAMSAY, Sir ANDREW CROMBIE, LL.D., F.R.S., F.G.S. 15 Cromwell-crescent, South Kensington, London, S.W.
1861. ‡Ramsay, John, M.P. Kildalton, Argyleshire.
1867. *Ramsay, W. F., M.D. 39 Hammersmith-road, West Kensington, London, W.
1876. ‡RAMSAY, WILLIAM, Ph.D., Professor of Chemistry in University College, Bristol.
1873. *Ramsden, William. Bracken Hall, Great Horton, Bradford, Yorkshire.
1835. *Rance, Henry. St. Andrew's-street, Cambridge.
1869. *Rance, H. W. Henniker, LL.M. 10 Castletown-road, West Kensington, London, S.W.
1860. ‡Randall, Thomas. Grandepoint House, Oxford.
1865. ‡Randel, J. 50 Vittoria-street, Birmingham.
Ranelagh, The Right Hon. Lord. 7 New Burlington-street, Regent-street, London, W.
1868. *Ransom, Edwin, F.R.G.S. Bedford.
1863. §Ransom, William Henry, M.D., F.R.S. The Pavement, Nottingham.
1861. ‡Ransome, Arthur, M.A. Bowdon, Manchester.
Ransome, Thomas. 34 Princess-street, Manchester.
1872. *Ranyard, Arthur Cowper, F.R.A.S. 25 Old-square, Lincoln's Inn, London, W.C.
Rashleigh, Jonathan. 3 Cumberland-terrace, Regent's Park, London, N.W.
RATCLIFF, Colonel CHARLES, F.L.S., F.G.S., F.S.A., F.R.G.S. Wyddrington, Edgbaston, Birmingham.
1864. ‡Rate, Rev. John, M.A. Lapley Vicarage, Penkridge, Staffordshire.
1870. ‡Rathbone, Benson. Exchange-buildings, Liverpool.
1870. ‡Rathbone, Philip H. Greenbank Cottage, Wavertree, Liverpool.
1870. §Rathbone, R. R. Beechwood House, Liverpool.
1863. ‡Rattray, W. St. Clement's Chemical Works, Aberdeen.
1874. ‡Ravenstein, E. G., F.R.G.S. 10 Lorn-road, Brixton, London, S.W.
Rawdon, William Frederick, M.D. Bootham, York.
1870. ‡Rawlins, G. W. The Hollies, Rainhall, Liverpool.
1866. *RAWLINSON, Rev. Canon GEORGE, M.A., Camden Professor of Ancient History in the University of Oxford. The Oaks, Precincts, Canterbury.
1855. *RAWLINSON, Major-General Sir HENRY C., K.C.B., LL.D., F.R.S., F.R.G.S. 21 Charles-street, Berkeley-square, London, W.
1875. §RAWSON, Sir RAWSON W., K.C.M.G., C.B., F.R.G.S. 68 Cornwall-gardens, Queen's-gate, London, S.W.
1868. *RAYLEIGH, The Right Hon. Lord, M.A., F.R.S., F.R.A.S., F.R.G.S., Professor of Experimental Physics in the University of Cambridge. 5 Salisbury-villas, Cambridge.

Year of Election.

1870. ‡Rayner, Joseph (Town Clerk). Liverpool.
1865. ‡Read, William. Albion House, Epworth, Rawtry.
*Read, W. H. Rudston, M.A., F.L.S. 12 Blake-street, York.
1870. §READE, THOMAS MELLARD, C.E., F.G.S. Blundellsands, Liverpool.
1862. *Readwin, Thomas Allison, M.R.I.A., F.G.S. 5 Crowhurst-road, Brixton, London, S.W.
1852. *REDFERN, Professor PETER, M.D. 4 Lower-crescent, Belfast.
1863. ‡Redmayne, Giles. 20 New Bond-street, London, W.
1863. ‡*Redmayne, R. R.* 12 *Victoria-terrace, Newcastle-on-Tyne.*
Redwood, Isaac. Cae Wern, near Neath, South Wales.
1861. ‡REED, Sir EDWARD J., K.C.B., M.P., F.R.S. 74 Gloucester-road, South Kensington, London, W.
1875. ‡Rees-Mogg, W. Wooldridge. Cholwell House, near Bristol.
1878. §Reichel, The Ven. Archdeacon, D.D. The Archdeaconry, Trim, Ireland.
1881. §Reid, Arthur S., B.A., F.G.S. 12 Bridge-street, Canterbury.
1876. ‡Reid, James. 10 Woodside-terrace, Glasgow.
1874. ‡*Reid, Robert, M.A.* 35 *Dublin-road, Belfast.*
1850. ‡Reid, William, M.D. Cruivie, Cupar, Fife.
1881. ‡Reid, William. 19½ Blake-street, York.
1875. §REINOLD, A. W., M.A., Professor of Physical Science. Royal Naval College, Greenwich, S.E.
1863. §RENALS, E. 'Nottingham Express' Office, Nottingham.
1863. ‡Rendel, G. Benwell, Newcastle-on-Tyne.
1867. ‡Renny, W. W. 8 Douglas-terrace, Broughty Ferry, Dundee.
1871. ‡REYNOLDS, JAMES EMERSON, M.A., F.R.S., F.C.S., M.R.I.A., Professor of Chemistry in the University of Dublin. The Laboratory, Trinity College, Dublin.
1870. *REYNOLDS, OSBORNE, M.A., F.R.S., Professor of Engineering in Owens College, Manchester. Fallowfield, Manchester.
1858. §REYNOLDS, RICHARD, F.C.S. 13 Briggate, Leeds.
1858. *Rhodes, John. 18 Albion-street, Leeds.
1877. *Rhodes, John. 360 Blackburn-road, Accrington, Lancashire.
1877. *Riccardi, Dr. Paul, Secretary of the Society of Naturalists. Via Stimmate, 15, Modena, Italy.
1863. ‡RICHARDSON, BENJAMIN WARD, M.A., M.D., F.R.S. 12 Hinde-street, Manchester-square, London, W.
1861. ‡Richardson, Charles. 10 Berkeley-square, Bristol.
1869. *Richardson, Charles. 4 Northumberland-avenue, Putney, S.W.
1863. *Richardson, Edward. 6 Stanley-terrace, Gosforth, Newcastle-on-Tyne.
1882. §Richardson, Rev. George, M.A. The College, Winchester.
1868. *Richardson, George. 4 Edward-street, Werneth, Oldham.
1870. ‡*Richardson, J. H.* 3 *Arundel-terrace, Cork.*
1870. ‡Richardson, Ralph. 16 Coates-crescent, Edinburgh.
Richardson, Thomas. Montpelier-hill, Dublin.
1881. ‡Richardson, W. B. Elm Bank, York.
1861. ‡Richardson, William. 4 Edward-street, Werneth, Oldham.
1876. §Richardson, William Haden. City Glass Works, Glasgow.
1863. ‡*Richter, Otto, Ph.D.* 6 *Derby-terrace, Glasgow.*
1870. ‡*Rickards, Dr.* 36 *Upper Parliament-street, Liverpool.*
1868. §RICKETTS, CHARLES, M.D., F.G.S. 22 Argyle-street, Birkenhead.
1877. ‡Ricketts, James, M.D. St. Helen's, Lancashire.
*RIDDELL, Major-General CHARLES J. BUCHANAN, C.B., R.A., F.R.S. Oaklands, Chudleigh, Devon.
1861. *Riddell, Henry B. Whitefield House, Rothbury, Morpeth.

Year of Election.

1872. ‡Ridge, James. 98 Queen's-road, Brighton.
1862. ‡Ridgway, Henry Ackroyd, B.A. Bank Field, Halifax.
1861. ‡Ridley, John. 19 Belsize-park, Hampstead, London, N.W.
1863. *Rigby, Samuel. Bruche Hall, Warrington.
1881. §Rigg, Arthur. 79 Warrington-crescent, London, W.
1873. ‡Ripley, Sir Edward, Bart. Acacia, Apperley, near Leeds.
*RIPON, The Most Hon. the Marquis of, K.G., D.C.L., F.R.S., F.L.S., F.R.G.S. 1 Carlton-gardens, London, S.W.
1867. ‡Ritchie, John. Fleuchar Craig, Dundee.
1855. ‡Ritchie, Robert, C.E. 14 Hill-street, Edinburgh.
1867. ‡Ritchie, William. Emslea, Dundee.
1869. *Rivington, John. Babbicombe, near Torquay.
1854. ‡Robberds, Rev. John, B.A. Battledown Tower, Cheltenham.
1869. *ROBBINS, JOHN, F.C.S. 57 Warrington-crescent, Maida Vale, London, W.
1878. ‡Roberts, Charles, F.R.C.S. 2 Bolton-row, London, W.
1859. ‡Roberts, George Christopher. Hull.
1870. *ROBERTS, ISAAC, F.G.S. Kennessee, Maghull, Lancashire.
1881. §Roberts, R. D., M.A., D.Sc., F.G.S. Clare College, Cambridge.
1879. ‡Roberts, Samuel. The Towers, Sheffield.
1879. ‡Roberts, Samuel, jun. The Towers, Sheffield.
1868. ‡ROBERTS, W. CHANDLER, F.R.S., F.G.S., F.C.S., Chemist to the Royal Mint, and Professor of Metallurgy in the Royal School of Mines. Royal Mint, London, E.
1859. ‡Robertson, Dr. Andrew. Indego, Aberdeen.
1871. ‡Robertson, George, C.E., F.R.S.E. 47 Albany-street, Edinburgh.
1870. *Robertson, John. 4 Albert-road, Southport.
1876. ‡Robertson, R. A. Newthorn, Ayton-road, Pollokshields, Glasgow.
1866. ‡ROBERTSON, WILLIAM TINDAL, M.D. Nottingham.
1861. ‡Robinson, Enoch. Dukinfield, Ashton-under-Lyne.
1852. ‡Robinson, Rev. George. Tartaraghan Glebe, Loughgall, Ireland.
1859. ‡Robinson, Hardy. 156 Union-street, Aberdeen.
*Robinson, H. Oliver. 34 Bishopsgate-street, London, E.C.
1873. §Robinson, Hugh. 82 Donegall-street, Belfast.
1861. ‡ROBINSON, JOHN, C.E. Atlas Works, Manchester.
1863. ‡Robinson, J. H. Cumberland-row, Newcastle-on-Tyne.
1878. ‡Robinson, John L., C.E. 198 Great Brunswick-street, Dublin.
1876. ‡Robinson, M. E. 6 Park-circus, Glasgow.
1881. §Robinson, Richard Atkinson. 195 Brompton-road, London, S.W.
1875. *Robinson, Robert, C.E., F.G.S. 2 West-terrace, Darlington.
1860. ‡Robinson, Admiral Sir Robert Spencer, K.C.B., F.R.S. 61 Eaton-place, London, S.W.
1863. ‡Robinson, T. W. U. Houghton-le-Spring, Durham.
1870. ‡Robinson, William. 40 Smithdown-road, Liverpool.
1882. §Robinson, W. Braham. Rosenheim, The Avenue, Southampton.
1870. *Robson, E. R. 41 Parliament-street, Westminster, S.W.
1876. ‡Robson, Hazleton R. 14 Royal-crescent West, Glasgow.
1855. ‡Robson, Neil, C.E. 127 St. Vincent-street, Glasgow.
1872. *Robson, William. Marchholm, Gillsland-road, Merchiston, Edinburgh.
1872. §RODWELL, GEORGE F., F.R.A.S., F.C.S. Marlborough College, Wiltshire.
1866. ‡Roe, Thomas. Grove-villas, Sitchurch.
1860. ‡ROGERS, JAMES E. THOROLD, M.P., Professor of Economic Science and Statistics in King's College, London. Beaumont-street, Oxford.

Year of Election.

1867. ‡Rogers, James S. Rosemill, by Dundee.
1869. *Rogers, Nathaniel, M.D. 87 South-street, Exeter.
1882. §Rogers, Rev. Saltren, M.A. Gwennap, Scorrier, Cornwall.
1870. ‡Rogers, T. L., M.D. Rainhill, Liverpool.
1876. §ROLLIT, A. K., B.A., LL.D., D.C.L., F.R.A.S., Hon. Fellow K.C.L. Thwaite House, Cottingham, East Yorkshire.
1876. ‡Romanes, George John, M.A., F.R.S., F.L.S. 18 Cornwall-terrace, Regent's Park, London, N.W.
1846. ‡Ronalds, Edmund, Ph.D. Stewartfield, Bonnington, Edinburgh.
1869. ‡Roper, C. H. Magdalen-street, Exeter.
1872. ‡Roper, Freeman Clarke Samuel, F.L.S., F.G.S. Palgrave House, Eastbourne.
1881. *Roper, W. O. Southfield, Lancaster.
1855. *ROSCOE, HENRY ENFIELD, B.A., Ph.D., LL.D., F.R.S., F.C.S., Professor of Chemistry in Owens College, Manchester.
1863. ‡Roseby, John. Haverholm House, Brigg, Lincolnshire.
1874. ‡Ross, Alexander Milton, M.A., M.D., F.G.S. Toronto, Canada.
1857. ‡Ross, David, LL.D. 32 Nelson-street, Dublin.
1880. §Ross, Captain G. E. A., F.R.G.S. Forfar House, Cromwell-road, London, S.W.
1872. ‡Ross, James, M.D. Tenterfield House, Waterfoot, near Manchester.
1859. *Ross, Rev. James Coulman. Baldon Vicarage, Oxford.
1874. ‡Ross, Rev. William. Chapelhill Manse, Rothesay, Scotland.
1880. ‡Ross, Colonel William Alexander. Acton House, Acton, London, W.
1869. *ROSSE, The Right Hon. the Earl of, B.A., D.C.L., LL.D., F.R.S., F.R.A.S., M.R.I.A. Birr Castle, Parsonstown, Ireland.
1865. *Rothera, George Bell. 17 Waverley-street, Nottingham.
1876. ‡Rottenburgh, Paul. 13 Albion-crescent, Glasgow.
1861. ‡Routh, Edward J., M.A., F.R.S., F.R.A.S., F.G.S. St. Peter's College, Cambridge.
1881. ‡Routh, Rev. William, M.A. Clifton Green, York.
1872. *Row, A. V. Nursing Observatory, Daba-gardens, Vizagapatam, India. (Care of Messrs. King & Co., 45 Pall Mall, London, S.W.)
1861. ‡Rowan, David. Elliot-street, Glasgow.
1881. ‡Rowe, Rev. G. Lord Mayor's Walk, York.
1865. §Rowe, Rev. John. Load Vicarage, Langport, Somerset.
1877. §ROWE, J. BROOKING, F.L.S., F.S.A. 16 Lockyer-street, Plymouth.
1881. ‡ROWE, R. C., M.A., Professor of Pure Mathematics in University College, London. University College, London, W.C.
1855. *ROWNEY, THOMAS H., Ph.D., F.C.S., Professor of Chemistry in Queen's College, Galway. Salerno, Salthill, Galway.
1881. *Rowntree, Joseph. 19 Bootham, York.
1881. *ROWNTREE, J. S. The Mount, York.
1862. ‡Rowsell, Rev. Evan Edward, M.A. Hambledon Rectory, Godalming.
1876. ‡Roxburgh, John. 7 Royal Bank-terrace, Glasgow.
1861. *Royle, Peter, M.D., L.R.C.P., M.R.C.S. 27 Lever-street, Manchester.
1875. ‡RÜCKER, A. W., M.A., Professor of Mathematics and Physics in the Yorkshire College, Leeds.
1869. §RUDLER, F. W., F.G.S. The Museum, Jermyn-street, London, S.W.
1882. §Rumball, Thomas, M.I.C.E. 3 Queen Anne's-gate, London, S.W.
1873. ‡*Rushforth, Joseph.* 43 *Ash-grove, Horton-lane, Bradford, Yorkshire.*
1847. ‡RUSKIN, JOHN, M.A., F.G.S., Slade Professor of Fine Arts in the University of Oxford. Brantwood, Coniston, Ambleside.

Year of Election.

1875. *Russell, The Hon. F. A. R. Pembroke Lodge, Richmond Park, Surrey.
1876. *Russell, George. 103 Blenheim-crescent, Notting Hill, London, W.
1865. ‡Russell, James, M.D. 91 Newhall-street, Birmingham.
Russell, John. 39 Mountjoy-square, Dublin.
1852. **Russell, Norman Scott.* *Sydenham.*
1876. §Russell, R., C.E., F.G.S. 1 Sea View, St. Bees, Carnforth.
1862. §RUSSELL, W. H. L., A.B., F.R.S. 3 Ridgmount-terrace, Highgate, London, N.
1852. *RUSSELL, WILLIAM J., Ph.D., F.R.S., F.C.S., Professor of Chemistry in St. Bartholomew's Medical College. 34 Upper Hamilton-terrace, St. John's Wood, London, N.W.
1875. ‡*Rutherford, David Greig.* *Surrey House, Forest Hill, London, S.E.*
1871. §RUTHERFORD, WILLIAM, M.D., F.R.S., F.R.S.E., Professor of the Institutes of Medicine in the University of Edinburgh.
1881. ‡Rutson, Albert. Newby Wiske, Thirsk.
Rutson, William. Newby Wiske, Northallerton, Yorkshire.
1879. ‡Ruxton, Captain Fitzherbert, R.N. 41 Cromwell-gardens, London, S.W.
1875. ‡Ryalls, Charles Wager, LL.D. 3 Brick-court, Temple, London, E.C.
1874. ‡Rye, E. C., F.Z.S., Librarian R.G.S. Royal Geographical Society, 1 Savile-row, London, W.
1865. ‡Ryland, Thomas. The Redlands, Erdington, Birmingham.
1861. *RYLANDS, THOMAS GLAZEBROOK, F.L.S., F.G.S. Highfields, Thelwall, near Warrington.

SABINE, General Sir EDWARD, K.C.B., R.A., LL.D., D.C.L., F.R.S., F.R.A.S., F.L.S., F.R.G.S. 13 Ashley-place, Westminster, S.W.
1871. ‡Sadler, Samuel Champernowne. Purton Court, Purton, near Swindon, Wiltshire.
1866. *St. Albans, His Grace the Duke of. Bestwood Lodge, Arnold, near Nottingham.
1880. ‡*Sakurai, J.* *96 Camden-street, London, N.W.*
1881. ‡Salkeld, William. 4 Paradise-terrace, Darlington.
1857. ‡SALMON, Rev. GEORGE, D.D., D.C.L., F.R.S., Regius Professor of Divinity in the University of Dublin. Trinity College, Dublin.
1873. *Salomons, Sir David, Bart. Broomhill, Tunbridge Wells.
1872. ‡SALVIN, OSBERT, M.A., F.R.S., F.L.S. Hawksfold, Haslemere.
1861. *Samson, Henry. 6 St. Peter's-square, Manchester.
1861. *Sandeman, Archibald, M.A. Garry Cottage, Perth.
1876. ‡Sandeman, David. Woodlands, Lenzie, Glasgow.
1878. ‡Sanders, Alfred, F.L.S. 2 Clarence-place, Gravesend, Kent.
1872. ‡Sanders, Mrs. 8 Powis-square, Brighton.
1872. ‡SANDERSON, J. S. BURDON, M.D., LL.D., F.R.S., Professor of Physiology in University College, London. 26 Gordon-square, London, W.C.
Sandes, Thomas, A.B. Sallow Glin, Tarbert, Co. Kerry.
1864. ‡Sandford, William. 9 Springfield-place, Bath.
1873. ‡Sands, T. C. 24 Spring-gardens, Bradford, Yorkshire.
1865. ‡*Sargant, W. L.* *Edmund-street, Birmingham.*
1868. ‡Saunders, A., C.E. King's Lynn.
1881. §SAUNDERS, HOWARD, F.L.S., F.Z.S. 7 Radnor-place, London, W.
1846. ‡SAUNDERS, TRELAWNEY W. India Office, London, S.W.
1864. ‡Saunders, T. W., Recorder of Bath. 1 Priory-place, Bath.

Year of Election.

1860. *Saunders, William. 3 Gladstone-terrace, Brighton.
1871. §Savage, W. D. Ellerslie House, Brighton.
1872. *Sawyer, George David. 55 Buckingham-place, Brighton.
1868. ‡Sawyer, John Robert. Grove-terrace, Thorpe Hamlet, Norwich.
1868. §Schacht, G. F. 7 Regent's-place, Clifton, Bristol.
1879. *Schäfer, E. A., F.R.S., M.R.C.S., Assistant Professor of Physiology in University College, London. Boreham Wood, Elstree, Herts.
*Schemmann, J. C. Hamburg. (Care of Messrs. Allen Everitt & Sons, Birmingham.)
1880. *Schemmann, Louis Carl. Hamburg. (Care of Messrs. Allen Everitt & Sons, Birmingham.)
1842. Schofield, Joseph. Stubley Hall, Littleborough, Lancashire.
1874. §Scholefield, Henry. Windsor-crescent, Newcastle-on-Tyne.
1876. ‡Schuman, Sigismond. 7 Royal Bank-place, Glasgow.
SCHUNCK, EDWARD, F.R.S., F.C.S. Oaklands, Kersall Moor, Manchester.
1873. *SCHUSTER, ARTHUR, Ph.D., F.R.S., F.R.A.S., Professor of Applied Mathematics in Owens College, Manchester.
1861. *Schwabe, Edmund Salis. Ryecroft House, Cheetham Hill, Manchester.
1847. *SCLATER, PHILIP LUTLEY, M.A., Ph.D., F.R.S., F.L.S., F.G.S., Sec. Zool. Soc. 11 Hanover-square, London, W.
1882. *SCLATER-BOOTH, The Right Hon. G., M.P., F.R.S. 74 St. George's-square, London, S.W.
1867. ‡SCOTT, ALEXANDER. Clydesdale Bank, Dundee.
1881. ‡Scott, Alexander, B.A., B.Sc. Trinity College, Cambridge.
1882. §Scott, Colonel A. de C., R.E. Ordnance Survey Office, Southampton.
1878. ‡Scott, Arthur William. St. David's College, Lampeter.
1881. ‡Scott, Miss Charlotte A. Girton College, Cambridge.
1876. ‡Scott, Mr. Bailie. Glasgow.
1871. ‡Scott, Rev. C. G. 12 Pilrig-street, Edinburgh.
1872. ‡Scott, Major-General H. Y. D., C.B., R.E., F.R.S. Sunnyside, Ealing, W.
1857. *SCOTT, ROBERT H., M.A., F.R.S., F.G.S., F.M.S., Secretary to the Council of the Meteorological Office. 6 Elm Park-gardens, London, S.W.
1861. §Scott, Rev. Robert Selkirk, D.D. 16 Victoria-crescent, Dowanhill, Glasgow.
1874. ‡Scott, Rev. Robinson, D.D. Methodist College, Belfast.
1858. ‡Scott, William. Holbeck, near Leeds.
1869. ‡Scott, William Bower. Chudleigh, Devon.
1881. *Scrivener, A. P. Weston Turvill, Tring.
1859. ‡Seaton, John Love. Hull.
1880. ‡Sedgwick, Adam, B.A. Trinity College, Cambridge.
1880. ‡Seebohm, Henry. F.L.S., F.Z.S. 6 Tenterden-street, Hanover-square, London, W.
1861. *SEELEY, HARRY GOVIER, F.R.S., F.L.S., F.G.S., F.R.G.S., F.Z.S., Professor of Geography in King's College, London. 14 Oppidans-road, Primrose Hill, London, N.W.
1855. ‡Seligman, H. L. 135 Buchanan-street, Glasgow.
1879. §Selim, Adolphus. 21 Mincing-lane, London, E.C.
1873. ‡Semple, R. H., M.D. 8 Torrington-square, London, W.C.
1858. *Senior, George, F.S.S. Rosehill, Dodworth, near Barnsley.
1870. *Sephton, Rev. J. 90 Huskisson-street, Liverpool.
1875. §Seville, Thomas. Blythe House, Southport, Lancashire.

Year of Election.

1873. ‡Sewell, Rev. E., M.A., F.G.S., F.R.G.S. Ilkley College, near Leeds
1868. ‡Sewell, Philip E. Catton, Norwich.
1861. **Seymour, Henry D.* *209 Piccadilly, London, W.*
*Shaen, William. 15 Upper Phillimore-gardens, Kensington, London, W.
1871. *Shand, James. Fullbrooks, Worcester Park, Surrey.
1867. §Shanks, James. Dens Iron Works, Arbroath, N.B.
1881. ‡Shann, George, M.D. Petergate, York.
1869. *Shapter, Dr. Lewis, LL.D. The Barnfield, Exeter.
1878. ‡SHARP, DAVID, M.B. Thornhill, Dumfriesshire.
Sharp, Rev. John, B.A. Horbury, Wakefield.
*Sharp, William, M.D., F.R.S., F.G.S. Horton House, Rugby.
Sharp, Rev. William, B.A. Mareham Rectory, near Boston, Lincolnshire.
1854. *Shaw, Charles Wright. 3 Windsor-terrace, Douglas, Isle of Man.
1870. ‡Shaw, Duncan. Cordova, Spain.
1865. ‡Shaw, George. Cannon-street, Birmingham.
1881. *Shaw, H. S. Hele, Professor of Engineering in University College, Bristol. 2 Pembroke-vale, Clifton, Bristol.
1870. ‡Shaw, John. 24 Great George-place, Liverpool.
1845. ‡Shaw, John, M.D., F.L.S., F.G.S. Hop House, Boston, Lincolnshire.
1878. ‡Shelford, W., C.E. 35A Great George-street, Westminster, S.W.
1881. §Shenstone, W. A. Clifton College, Bristol.
1863. ‡Shepherd, A. B. 49 Seymour-street, Portman-square, London, W.
1870. §Shepherd, Joseph. 29 Everton-crescent, Liverpool.
Sheppard, Rev. Henry W., B.A. The Parsonage, Emsworth, Hants.
1880. ‡Shida, R. 1 St. James's-place, Hillhead, Glasgow.
1866. ‡Shilton, Samuel Richard Parr. Sneinton House, Nottingham.
1867. ‡Shinn, William C. 4 Varden's-road, Clapham Junction, Surrey, S.W.
1870. *SHOOLBRED, JAMES N., C.E., F.G.S. 3 Westminster-chambers, London, S.W.
1875. ‡Shore, Thomas W., F.C.S., F.G.S. Hartley Institution, Southampton.
1882. §Shore, T. W., jun., B.Sc. Uplands, Woolston, Southampton.
1881. §Shuter, James L. Lawn House, Tufnell Park, London, N.
1861. *Sidebotham, Joseph. The Beeches, Bowdon, Cheshire.
1877. *Sidebotham, Joseph Watson. The Beeches, Bowdon, Cheshire.
1873. ‡Sidgwick, R. H. The Raikes, Skipton.
Sidney, M. J. F. Cowpen, Newcastle-upon-Tyne.
1873. *Siemens, Alexander. 12 Queen Anne's-gate, Westminster, S.W.
1856. *SIEMENS, C. WILLIAM, D.C.L., LL.D., F.R.S., F.C.S., M.I.C.E. (PRESIDENT.) 12 Queen Anne's-gate, Westminster, S.W.
1878. ‡Sigerson, Professor George, M.D., F.L.S., M.R.I.A. 3 Clare-street, Dublin.
1859. ‡Sim, John. Hardgate, Aberdeen.
1871. ‡Sime, James. Craigmount House, Grange, Edinburgh.
1865. ‡Simkiss, T. M. Wolverhampton.
1862. ‡Simms, James. 138 Fleet-street, London, E.C.
1874. ‡Simms, William. The Linen Hall, Belfast.
1876. ‡Simon, Frederick. 24 Sutherland-gardens, London, W.
1847. ‡Simon, John, C.B., D.C.L., F.R.S., F.R.C.S., Surgeon to St. Thomas's Hospital. 40 Kensington-square, London, W.
1866. ‡Simons, George. The Park, Nottingham.

Year of Election.

1871. *SIMPSON, ALEXANDER R., M.D., Professor of Midwifery in the University of Edinburgh. 52 Queen-street, Edinburgh.
1867. ‡Simpson, G. B. Seafield, Broughty Ferry, by Dundee.
1859. ‡Simpson, John. Maykirk, Kincardineshire.
1863. ‡Simpson, J. B., F.G.S. Hedgefield House, Blaydon-on-Tyne.
1857. ‡SIMPSON, MAXWELL, M.D., LL.D., F.R.S., F.C.S., Professor of Chemistry in Queen's College, Cork.
1876. ‡*Simpson, Robert. 14 Ibrox-terrace, Glasgow.*
Simpson, William. Bradmore House, Hammersmith, London, W.
1876. ‡*Sinclair, James. Titwood Bank, Pollockshields, near Glasgow.*
1874. ‡Sinclair, Thomas. Dunedin, Belfast.
1834. ‡Sinclair, Vetch, M.D. 48 Albany-street, Edinburgh.
1870. *Sinclair, W. P. 19 Devonshire-road, Prince's Park, Liverpool.
1864. *Sircar, Mahendra Lal, M.D. 51 Sankaritola, Calcutta. (Care of Messrs. S. Harraden & Co., 3 Hill's-place, Oxford-street, London, W.)
1865. ‡Sissons, William. 92 Park-street, Hull.
1879. ‡Skertchly, Sydney B. J., F.G.S. Geological Museum, Jermyn-street, London, S.W.
1870. §SLADEN, WALTER PERCY, F.G.S., F.L.S. Exley House, near Halifax.
1873. ‡Slater, Clayton. Barnoldswick, near Leeds.
1873. ‡*Slater, W. B. 42 Clifton Park-avenue, Belfast.*
1842. *Slater, William. Park-lane, Higher Broughton, Manchester.
1877. ‡Sleeman, Rev. Philip, L.Th., F.R.A.S., F.R.M.S. Clifton, Bristol.
1849. ‡Sloper, George Elgar. Devizes.
1849. ‡Sloper, Samuel W. Devizes.
1860. ‡Sloper, S. Elgar. Winterton, near Hythe, Southampton.
1867. ‡Small, David. Gray House, Dundee.
1881. ‡Smallshan, John. 81 Manchester-road, Southport.
1858. ‡Smeeton, G. H. Commercial-street, Leeds.
1876. ‡Smeiton, James. Panmure Villa, Broughty Ferry, Dundee.
1876. ‡Smeiton, John G. Panmure Villa, Broughty Ferry, Dundee.
1867. ‡Smeiton, Thomas A. 55 Cowgate, Dundee.
1876. §Smellie, Thomas D. 213 St. Vincent-street, Glasgow.
1877. ‡Smelt, Rev. Maurice Allen, M.A., F.R.A.S. Heath Lodge, Cheltenham.
1857. ‡Smith, Aquilla, M.D., M.R.I.A. 121 Lower Baggot-street, Dublin.
1868. ‡*Smith, Augustus. Northwood House, Church-road, Upper Norwood, Surrey, S.E.*
1872. *Smith, Basil Woodd, F.R.A.S. Branch Hill Lodge, Hampstead Heath, London, N.W.
1874. *Smith, Benjamin Leigh. 64 Gower-street, London, W.C.
1873. ‡Smith, C. Sidney College, Cambridge.
1865. ‡SMITH, DAVID, F.R.A.S. 40 Bennett's-hill, Birmingham.
1865. ‡Smith, Frederick. The Priory, Dudley.
1866. *Smith, F. C. Bank, Nottingham.
1855. ‡Smith, George. Port Dundas, Glasgow.
1876. ‡Smith, George. Glasgow.
*SMITH, HENRY JOHN STEPHEN, M.A., LL.D., F.R.S., F.R.A.S., F.C.S., Savilian Professor of Geometry in the University of Oxford, and Keeper of the University Museum. The Museum, Oxford.
1860. *Smith, Heywood, M.A., M.D. 18 Harley-street, Cavendish-square, London, W.
1870. ‡Smith, H. L. Crabwall Hall, Cheshire.
1870. ‡*Smith, James. 146 Bedford-street South, Liverpool.*
1871. *Smith, John Alexander, M.D., F.R.S.E. 10 Palmerston-place, Edinburgh.

Year of Election.

1876. *Smith, J. Guthrie. 173 St. Vincent-street, Glasgow.
1874. ‡Smith, John Haigh. Beech Hill, Halifax, Yorkshire.
Smith, John Peter George. Sweyney Cliff, near Coalport, Shropshire.
1871. ‡Smith, Professor J. William Robertson. Free Church College, Aberdeen.
*Smith, Philip, B.A. The Bays, Parkfields, Putney, S.W.
1860. *Smith, Protheroe, M.D. 42 Park-street, Grosvenor-square, London, W.
1837. Smith, Richard Bryan. Villa Nova, Shrewsbury.
1847. §SMITH, ROBERT ANGUS, Ph.D., F.R.S., F.C.S. 22 Devonshire-street, Manchester.
*Smith, Robert Mackay. 4 Bellevue-crescent, Edinburgh.
1870. ‡Smith, Samuel. Bank of Liverpool, Liverpool.
1866. ‡Smith, Samuel. 33 Compton-street, Goswell-road, London, E.C.
1873. ‡Smith, Swire. Lowfield, Keighley, Yorkshire.
1867. ‡Smith, Thomas. Dundee.
1867. ‡Smith, Thomas. Poole Park Works, Dundee.
1859. ‡Smith, Thomas James, F.G.S., F.C.S. Hessle, near Hull.
1852. ‡Smith, William. Eglinton Engine Works, Glasgow.
1875. *Smith, William. Sundon House, Clifton, Bristol.
1876. ‡Smith, William. 12 Woodside-place, Glasgow.
1878. ‡Smithson, Joseph S. Balnagowan, Rathmines, Co. Dublin.
1883. §Smithson, T. Spencer. Facit, Rochdale.
1874. ‡Smoothy, Frederick. Bocking, Essex.
1850. *SMYTH, CHARLES PIAZZI, F.R.S.E., F.R.A.S., Astronomer Royal for Scotland, Professor of Astronomy in the University of Edinburgh. 15 Royal-terrace, Edinburgh.
1874. ‡Smyth, Henry, C.E. Downpatrick, Ireland.
1870. ‡Smyth, Colonel H. A., R.A. Barrackpore, near Calcutta.
1878. §Smyth, Mrs. Isabella. Wigmore Lodge, Cullenswood-avenue, Dublin.
1857. *SMYTH, JOHN, jun., M.A., C.E., F.M.S. Lenaderg, Banbridge, Ireland.
1864. ‡SMYTH, WARINGTON W., M.A., F.R.S., F.G.S., F.R.G.S., Lecturer on Mining and Mineralogy at the Royal School of Mines, and Inspector of the Mineral Property of the Crown. 5 Inverness-terrace, Bayswater, London, W.
1854. ‡Smythe, Lieut.-General W. J., R.A., F.R.S. Athenæum Club, Pall Mall, London, S.W.
1878. §Snell, H. Saxon. 22 Southampton-buildings, London, W.C.
1879. §SOLLAS, W. J., M.A., F.R.S.E., F.G.S., Professor of Geology in University College, Bristol.
*SOLLY, EDWARD, F.R.S., F.L.S., F.G.S., F.S.A. Camden House, Sutton, Surrey.
Sorbey, Alfred. The Rookery, Ashford, Bakewell.
1859. *SORBY, H. CLIFTON, LL.D., F.R.S., F.G.S. Broomfield, Sheffield.
1879. *Sorby, Thomas W. Storthfield, Sheffield.
1865. *Southall, John Tertius. Parkfields, Ross, Herefordshire.
1859. ‡Southall, Norman. 44 Cannon-street West, London, E.C.
1856. ‡Southwood, Rev. T. A. Cheltenham College.
1863. ‡Sowerby, John. Shipcote House, Gateshead, Durham.
1863. *Spark, H. King. Starforth House, Barnard Castle.
1879. ‡Spence, David. Brookfield House, Freyinghall, Yorkshire.
1869. *Spence, J. Berger. Erlington House, Manchester.
1854. §Spence, Peter, F.C.S. Erlington House, Seymour-grove, Manchester.
1881. ‡Spencer, Herbert E. Lord Mayor's Walk, York.

Year of Election.

1861. ‡Spencer, John Frederick. 28 Great George-street, London, S.W.
1861. *Spencer, Joseph. Springbank, Old Trafford, Manchester.
1863. *Spencer, Thomas. The Grove, Ryton, Blaydon-on-Tyne, Co. Durham.
1875. ‡Spencer, W. H. Richmond Hill, Clifton, Bristol.
1864. *Spicer, Henry, B.A., F.L.S., F.G.S. 14 Aberdeen Park, Highbury, London, N.
1864. §Spicer, William R. 19 New Bridge-street, Blackfriars, London, E.C.
1864. *SPILLER, JOHN, F.C.S. 2 St. Mary's-road, Canonbury, London, N.
1878. §Spottiswoode, George Andrew. 3 Cadogan-square, London, S.W.
1846. *SPOTTISWOODE, WILLIAM, M.A., D.C.L., LL.D., Pres. R.S., F.R.A.S., F.R.G.S. 41 Grosvenor-place, London, S.W.
1864. *Spottiswoode, W. Hugh. 41 Grosvenor-place, London, S.W.
1854. *SPRAGUE, THOMAS BOND, M.A., F.R.S.E. 29 Buckingham-terrace, Edinburgh.
1853. ‡Spratt, Joseph James. West Parade, Hull.
Square, Joseph Elliot, F.G.S. 24 Portland-place, Plymouth.
1877. ‡SQUARE, WILLIAM, F.R.C.S., F.R.G.S. 4 Portland-square, Plymouth.
*Squire, Lovell. 4 Brackenbury-road, Hammersmith, London, W.
1879. ‡Stacye, Rev. John. Shrewsbury Hospital, Sheffield.
1858. *STAINTON, HENRY T., F.R.S., F.L.S., F.G.S. Mountsfield, Lewisham, S.E.
1865. ‡STANFORD, EDWARD C. C. Glenwood, Dalmuir, N.B.
1837. ·Staniforth, Rev. Thomas. Storrs, Windermere.
1881. §Stanley, William Ford. Cumberlow, South Norwood, Surrey, S.E.
Stapleton, M. H., M.B., M.R.I.A. 1 Mountjoy-place, Dublin.
1866. ‡Starey, Thomas R. Daybrook House, Nottingham.
1876. §Starling, John Henry, F.C.S. The Avenue, Erith, Kent.
Staveley, T. K. Ripon, Yorkshire.
1873. *Stead, Charles. Saltaire, Bradford, Yorkshire.
1881. §Stead, W. H. Southport, Lancashire.
1881. §Stead, Mrs. W. H. Southport, Lancashire.
1857. ‡Steale, William Edward, M.D. 15 Hatch-street, Dublin.
1870. ‡Stearn, C. H. 2 St. Paul's-villas, Rock Ferry, Liverpool.
1863. ‡Steele, Rev. Dr. 35 Sydney-buildings, Bath.
1873. §Steinthal, G. A. 15 Hallfield-road, Bradford, Yorkshire.
1861. †Steinthal, H. M. Hollywood, Fallowfield, near Manchester.
1872. ‡Stennett, Mrs. Eliza. 2 Clarendon-terrace, Brighton.
1879. *STEPHENSON, HENRY, J.P. Endcliffe Vale, Sheffield.
1881. ‡Stephenson, J. F. 3 Mount-parade, York.
1861. *Stern, S. J. Littlegrove, East Barnet, Herts.
1863. ‡Sterriker, John. Driffield, Yorkshire.
1876. ‡Steuart, Walter. City Bank, Pollockshaws, near Glasgow.
1870. *Stevens, Miss Anna Maria. Belmont, Devizes-road, Salisbury.
1861. *Stevens, Henry, F.S.A., F.R.G.S. 4 Trafalgar-square, London, W.C.
1880. *Stevens, J. Edward. 10 Cleveland-terrace, Swansea.
1868. ‡Stevenson, Henry, F.L.S. Newmarket-road, Norwich.
1878. ‡Stevenson, Rev. James, M.A. 21 Garville-avenue, Rathgar, Dublin.
1863. *STEVENSON, JAMES C., M.P., F.C.S. Westoe, South Shields.
1882. §Steward, Rev. C. E., M.A. The Polygon, Southampton.
1855. ‡STEWART, BALFOUR, M.A., LL.D., F.R.S., Professor of Natural Philosophy in Owens College, Manchester.
1864. ‡STEWART, CHARLES, M.A., F.L.S. St. Thomas's Hospital, London, S.E.

Year of Election.

1875. *Stewart, James, B.A., M.R.C.P.Ed. Dunmurry, Sneyd Park, near Bristol.
1876. ‡Stewart, William. Violet Grove House, St. George's-road, Glasgow.
1867. ‡Stirling, Dr. D. Perth.
1868. ‡*Stirling, Edward. 34 Queen's-gardens, Hyde Park, London, W.*
1876. ‡Stirling, William, M.D., D.Sc. The University, Aberdeen.
1867. *Stirrup, Mark, F.G.S. 14 Atkinson-street, Deansgate, Manchester.
1865. *Stock, Joseph S. The Grange, Ramsgate.
1864. ‡Stoddart, William Walter, F.G.S., F.C.S. Grafton Lodge, Sneyd Park, Bristol.
1854. ‡Stoess, Le Chevalier Ch. de W. (Bavarian Consul). Liverpool.
*Stokes, George Gabriel, M.A., D.C.L., LL.D., Sec. R.S., Lucasian Professor of Mathematics in the University of Cambridge. Lensfield Cottage, Cambridge.
1862. ‡Stone, Edward James, M.A., F.R.S., F.R.A.S., Director of the Radcliffe Observatory, Oxford.
1874. ‡Stone, J. Harris, B.A., F.L.S., F.C.S. 11 Sheffield-gardens, Kensington, London, W.
1876. ‡Stone, Octavius C., F.R.G.S. Springfield, Nuneaton.
1859. ‡Stone, Dr. William H. 14 Dean's-yard, Westminster, S.W.
1857. ‡Stoney, Bindon B., C.E., F.R.S. M.R.I.A., Engineer of the Port of Dublin. 42 Wellington-road, Dublin.
1878. *Stoney, G. Gerald. 3 Palmerston Park, Dublin.
1861. *Stoney, George Johnstone, M.A., F.R.S., M.R.I.A., Secretary to the Queen's University, Ireland. 3 Palmerston Park, Dublin.
1876. §Stopes, Henry, F.G.S. Kenwyn, Cintra Park, Upper Norwood, S.E.
1854. Store, George. Prospect House, Fairfield, Liverpool.
1873. ‡Storr, William. The 'Times' Office, Printing-house-square, London, E.C.
1867. ‡*Storrar, John, M.D. Heathview, Hampstead, London, N.W.*
1859. §Story, Captain James. 17 Bryanston-square, London, W.
1874. ‡Stott, William. Greetland, near Halifax, Yorkshire.
1871. *Strachey, Lieut.-General Richard, R.E., C.S.I., F.R.S., F.R.G.S., F.L.S, F.G.S. Stowey House, Clapham Common, London, S.W.
1881. ‡Strahan, Aubrey, M.A., F.G.S. Geological Museum, Jermyn-street, London, S.W.
1876. ‡Strain, John. 143 West Regent-street, Glasgow.
1863. ‡Straker, John. Wellington House, Durham.
1882. §Strange, Rev. Cresswell, M.A. Holy Trinity Vicarage, Southampton.
1881. ‡Strangways, C. Fox, F.G.S. Geological Museum, Jermyn-street, London, S.W.
*Strickland, Charles. Loughglyn House, Castlerea, Ireland.
1879. ‡Strickland, Sir Charles W., K.C.B. Hildenley-road, Malton.
Strickland, William. French Park, Roscommon, Ireland.
1859. ‡Stronach, William, R.E. Ardmellie, Banff.
1867. ‡Stronner, D. 14 Princess-street, Dundee.
1876. *Struthers, John, M.D., Professor of Anatomy in the University of Aberdeen.
1878. ‡Strype, W. G., C.E. Wicklow.
1876. *Stuart, Charles Maddock. Roneth Lodge, Harrow.
1872. *Stuart, Rev. Edward A. 22 Bedford-street, Norwich.
1873. ‡Style, Rev. George, M.A. Giggleswick School, Yorkshire.
1879. *Styring, Robert. 3 Hartshead, Sheffield.
1857. ‡Sullivan, William K., Ph.D., M.R.I.A. Queen's College, Cork.
1873. ‡Sutcliffe, J. W. Sprink Bank, Bradford, Yorkshire.

Year of Election.

1873. ‡Sutcliffe, Robert. Idle, near Leeds.
1863. ‡Sutherland, Benjamin John. 10 Oxford-street, Newcastle-on-Tyne.
1862. *SUTHERLAND, GEORGE GRANVILLE WILLIAM, Duke of, K.G., F.R.S., F.R.G.S. Stafford House, London, S.W.
1863. ‡SUTTON, FRANCIS, F.C.S. Bank Plain, Norwich.
1881. §Sutton, William. Town Hall, Southport.
1881. ‡Swales, William. Ashville, Holgate-road, York.
1876. ‡Swan, David, jun. Braeside, Maryhill, Glasgow.
1881. §Swan, Joseph W. Mosley-street, Newcastle-on-Tyne.
1861. *Swan, Patrick Don S. Kirkcaldy, N.B.
1862. *SWAN, WILLIAM, LL.D., F.R.S.E., Professor of Natural Philosophy in the University of St. Andrews, N.B.
1862. *Swann, Rev. S. Kirke, F.R.A.S. Forest Hill Lodge, Warsop, Mansfield, Nottinghamshire.
1879. §Swanwick, Frederick. Whittington, Chesterfield.
Sweetman, Walter, M.A., M.R.I.A. 4 Mountjoy-square North, Dublin.
1870. *Swinburne, Sir John, Bart. Capheaton, Newcastle-on-Tyne.
1863. ‡Swindell, J. S. E. Summerhill, Kingswinford, Dudley.
1873. *Swinglehurst, Henry. Hincaster House, near Milnthorpe.
1873. §Sykes, Benjamin Clifford, M.D. Cleckheaton.
1847. ‡Sykes, H. P. 47 Albion-street, Hyde Park, London, W.
1862. ‡Sykes, Thomas. Cleckheaton.
1847. ‡Sykes, Captain W. H. F. 47 Albion-street, Hyde Park, London, W.
SYLVESTER, JAMES JOSEPH, M.A., LL.D., F.R.S. Athenæum Club, London, S.W.
1870. ‡SYMES, RICHARD GLASCOTT, A.B., F.G.S. Geological Survey of Ireland, 14 Hume-street, Dublin.
1881. §Symington, Thomas. 13 Dundas-street, Edinburgh.
1856. *Symonds, Frederick, M.A., F.R.C.S. 35 Beaumont-street, Oxford.
1859. ‡Symonds, Captain Thomas Edward, R.N. 10 Adam-street, Adelphi, London, W.C.
1860. ‡SYMONDS, Rev. W. S., M.A., F.G.S. Pendock Rectory, Worcestershire.
1859. §SYMONS, G. J., F.R.S., Sec.M.S. 62 Camden-square, London, N.W.
1855. *SYMONS, WILLIAM, F.C.S. 26 Joy-street, Barnstaple.
Synge, Francis. Glanmore, Ashford, Co. Wicklow.
1872. ‡Synge, Major-General Millington, R.E., F.S.A., F.R.G.S. United Service Club, Pall Mall, London, S.W.

1865. ‡Tailyour, Colonel Renny, R.E. Newmanswalls, Montrose, N.B.
1877. *TAIT, LAWSON, F.R.C.S. 7 Great Charles-street, Birmingham.
1871. ‡TAIT, PETER GUTHRIE, F.R.S.E., Professor of Natural Philosophy in the University of Edinburgh. George-square, Edinburgh.
1867. ‡TAIT, P. M., F.R.G.S., F.S.S. Oriental Club, Hanover-square, London, W.
1874. §Talmage, C. G., F.R.A.S. Leyton Observatory, Essex, E.
1866. ‡Tarbotton, Marrott Ogle, M.I.C.E., F.G.S. Newstead-grove, Nottingham.
1878. ‡TARPEY, HUGH. Dublin.
1861. *Tarratt, Henry W. 9 Magdala-villas, Margate.
1856. ‡Tartt, William Macdonald, F.S.S. Sandford-place, Cheltenham.
1857. *Tate, Alexander, C.E. Longwood, Whitehouse, Belfast.
1863. ‡*Tate, John. Alnmouth, near Alnwick, Northumberland.*
1870. ‡Tate, Norman A. 7 Nivell-chambers, Fazackerley-street, Liverpool.

Year of Election.

1858. *Tatham, George, J.P. Springfield Mount, Leeds.
1876. ‡Tatlock, Robert R. 26 Burnbank-gardens, Glasgow.
1879. ‡Tattershall, William Edward. 15 North Church-street, Sheffield.
1878. *Taylor, A. Claude. Clinton-terrace, Derby-road, Nottingham.
1874. ‡Taylor, Alexander O'Driscoll. 3 Upper-crescent, Belfast.
1867. ‡Taylor, Rev. Andrew. Dundee.
1880. §Taylor, Edmund. Droitwich.
Taylor, Frederick. Laurel Cottage, Rainhill, near Prescot, Lancashire.
1874. ‡Taylor, G. P. Students' Chambers, Belfast.
1881. *Taylor, H. A. 112 Cromwell-road, London, S.W.
1882. *Taylor, Herbert Owen, M.D. 17 Castlegate, Nottingham.
1879. ‡Taylor, John. Broomhall-place, Sheffield.
1861. *Taylor, John. 6 Queen-street-place, Upper Thames-street, London, E.C.
1873. ‡Taylor, John Ellor, Ph.D., F.L.S., F.G.S. The Mount, Ipswich.
1881. *Taylor, John Francis. Holly Bank House, York.
1865. ‡Taylor, Joseph. 99 Constitution-hill, Birmingham.
*Taylor, Richard, F.G.S. 6 Gledhow-gardens, South Kensington, London, S.W.
1876. ‡Taylor, Robert. 70 Bath-street, Glasgow.
1878. ‡Taylor, Robert, J.P., LL.D. Corballis, Drogheda.
1881. ‡Taylor, Rev. S. B., M.A., Chaplain of Lower Assam, Gauhatti, Assam. (Care of Messrs. Grindlay & Co., 55 Parliament-street, London, S.W.)
1870. ‡Taylor, Thomas. Aston Rowant, Tetsworth, Oxon.
*Taylor, William Edward. Woodlands, Harrow.
1858. ‡Teale, Thomas Pridgin, jun. 20 Park-row, Leeds.
1880. ‡Tebb, Miss. 7 Albert-road, Regent's Park, London, N.W.
1869. ‡Teesdale, C. S. M. Whyke House, Chichester.
1876. ‡Temperley, Ernest. Queen's College, Cambridge.
1879. §Temple, Lieutenant George T., R.N., F.R.G.S. 4 West Pier, London Dock, London, E.
1880. §Temple, Sir Richard, Bart., G.C.S.I., D.C.L., F.R.G.S. Athenæum Club, London, S.W.
1863. ‡Tennant, Henry. Saltwell, Newcastle-on-Tyne.
1882. §Terrill, William. 3 Hanover-street, Swansea.
1881. ‡Terry, Mr. Alderman. Mount-villas, York.
1866. ‡Thackeray, J. L. Arno Vale, Nottingham.
1882. *Thane, George Dancer, Professor of Anatomy in University College, Gower-street, London, W.C.
1871. ‡Thin, James. 7 Rillbank-terrace, Edinburgh.
1871. ‡Thiselton-Dyer, W. T., M.A., B.Sc., F.R.S., F.L.S. 11 Brunswick-villas, Kew Gardens-road, Kew.
1835. Thom, John. Lark-hill, Chorley, Lancashire.
1870. ‡Thom, Robert Wilson. Lark-hill, Chorley, Lancashire.
1879. *Thomas, Arthur. Endcliffe House, Sheffield.
1871. ‡Thomas, Ascanius William Nevill. Chudleigh, Devon.
1875. *Thomas, Christopher James. Drayton Lodge, Redland, Bristol.
Thomas, George. Brislington, Bristol.
1875. ‡Thomas, Herbert. Ivor House, Redlands, Bristol.
1869. ‡Thomas, H. D. Fore-street, Exeter.
1881. §Thomas, J. Blount. Southampton.
1869. ‡Thomas, J. Henwood, F.R.G.S. Custom House, London, E.C.
1880. *Thomas, Joseph William, F.C.S. The Laboratory, West Wharf, Cardiff.

Year of
Election.

1881. §Thomas, Sydney G. 27 Tedworth-square, London, S.W.
1875. ‡Thompson, Arthur. 12 St. Nicholas-street, Hereford.
1882. §Thompson, Charles O. Terre Haute, Indiana, U.S.A.
1859. ‡Thompson, George, jun. Pidsmedden, Aberdeen.
Thompson, Harry Stephen. Kirby Hall, Great Ouseburn, Yorkshire.
1870. ‡THOMPSON, Sir HENRY. 35 Wimpole-street, London, W.
Thompson, Henry Stafford. Fairfield, near York.
1861. *Thompson, Joseph. Riversdale, Wilmslow, Manchester.
1864. ‡THOMPSON, Rev. JOSEPH HESSELGRAVE, B.A. Cradley, near Brierley Hill.
1873. ‡Thompson, M. W. Guiseley, Yorkshire.
1876. *Thompson, Richard. Park-street, The Mount, York.
1874. ‡Thompson, Robert. Walton, Fortwilliam Park, Belfast.
1876. §THOMPSON, SILVANUS PHILLIPS, B.A., D.Sc., F.R.A.S., Professor of Physics in University College, Bristol.
1863. ‡Thompson, William. 11 North-terrace, Newcastle-on-Tyne.
1867. ‡Thoms, William. Magdalen-yard-road, Dundee.
1855. ‡THOMSON, ALLEN, M.D., LL.D., F.R.S. L. & E. 66 Palace Gardens-terrace, Kensington, London, W.
Thomson, Guy. Oxford.
1850. *THOMSON, Professor JAMES, M.A., LL.D., C.E., F.R.S. L. & E. The University, Glasgow.
1868. §THOMSON, JAMES, F.G.S. 3 Abbotsford-place, Glasgow.
*Thomson, James Gibson. 14 York-place, Edinburgh.
1876. ‡Thomson, James R. Dalmuir House, Dalmuir, Glasgow.
1874. ‡*Thomson, John. Harbour Office, Belfast.*
1871. *THOMSON, JOHN MILLAR, F.C.S. King's College, London, W.C.
1871. ‡Thomson, Robert, LL.B. 12 Rutland-square, Edinburgh.
1847. *THOMSON, Sir WILLIAM, M.A., LL.D., D.C.L., F.R.S. L. & E., F.R.A.S., Professor of Natural Philosophy in the University of Glasgow. The University, Glasgow.
1877. *Thomson, Lady. The University, Glasgow.
1874. §THOMSON, WILLIAM, F.R.S.E., F.C.S. Royal Institution, Manchester.
1876. ‡*Thomson, William. 6 Mansfield-place, Edinburgh.*
1880. §Thomson, William J. St. Helen's, Lancashire.
1871. ‡Thornburn, Rev. David, M.A. 1 John's-place, Leith.
1852. ‡Thornburn, Rev. William Reid, M.A. Starkies, Bury, Lancashire.
*Thornton, Samuel, J.P. Oakfield, Moseley, near Birmingham.
1867. ‡Thornton, Thomas. Dundee.
1845. ‡Thorp, Dr. Disney. Lyppiatt Lodge, Suffolk Lawn, Cheltenham.
1881. ‡Thorp, Fielden. Blossom-street, York.
1871. ‡Thorp, Henry. Briarleigh, Sale, near Manchester.
1881. *Thorp, Josiah. New Mills, near Huddersfield.
1864. *THORP, WILLIAM, B.Sc., F.C.S. 39 Sandringham-road, Kingsland, London, E.
1871. ‡THORPE, T. E., Ph.D., F.R.S. L. & E., F.C.S., Professor of Chemistry in Yorkshire College, Leeds.
1868. ‡THUILLIER, Lieut.-General Sir H. E. L., R.A., C.S.I., F.R.S., F.R.G.S. 32 Cambridge-terrace, Hyde Park, London, W.
1870. ‡Tichborne, Charles R. C., LL.D., F.C.S., M.R.I.A. Apothecaries' Hall of Ireland, Dublin.
1873. *TIDDEMAN, R. H., M.A., F.G.S. 28 Jermyn-street, London, S.W.
1874. ‡TILDEN, WILLIAM A., D.Sc., F.R.S., F.C.S., Professor of Chemistry and Metallurgy in the Mason Science College, Birmingham. 36 Frederick-road, Birmingham.

Year of Election.

1873. ‡Tilghman, B. C. Philadelphia, United States.
Tinker, Ebenezer. Mealhill, near Huddersfield.
*TINNE, JOHN A., F.R.G.S. Briarley, Aigburth, Liverpool.
1876. ‡Todd, Rev. Dr. Tudor Hall, Forest Hill, London, S.E.
1861. *TODHUNTER, ISAAC, M.A., F.R.S. Brookside, Cambridge.
1857. ‡Tombe, Rev. Canon. Glenealy, Co. Wicklow.
1856. ‡Tomes, Robert Fisher. Welford, Stratford-on-Avon.
1864. *TOMLINSON, CHARLES, F.R.S., F.C.S. 7 North-road, Highgate, London, N.
1865. §Tonks, Edmund, B.C.L. Packwood Grange, Knowle, Warwickshire.
1865. *Tonks, William Henry. The Rookery, Sutton Coldfield.
1873. *Tookey, Charles, F.C.S. Royal School of Mines, Jermyn-street, London, S.W.
1861. *Topham, John, M.I.C.E. High Elms, 265 Mare-street, Hackney, London, E.
1872. *TOPLEY, WILLIAM, F.G.S., A.I.C.E. Geological Survey Office, Jermyn-street, London, S.W.
1875. §Torr, Charles Hawley. Harrowby House, Park-row, Nottingham.
1863. ‡Torrens, Colonel Sir R. R., K.C.M.G. 12 Chester-place, Hyde Park, London, W.
1859. ‡Torry, Very Rev. John, Dean of St. Andrews. Coupar Angus, N.B.
Towgood, Edward. St. Neot's, Huntingdonshire.
1873. ‡Townend, W. H. Heaton Hall, Bradford, Yorkshire.
1875. ‡Townsend, Charles. Avenue House, Cotham Park, Bristol.
1857. *TOWNSEND, Rev. RICHARD, M.A., F.R.S., Professor of Natural Philosophy in the University of Dublin. Trinity College, Dublin.
1861. ‡Townsend, William. Attleborough Hall, near Nuneaton.
1877. ‡Tozer, Henry. Ashburton.
1876. *Trail, Professor J. W. H., M.A., M.D., F.L.S. University of Aberdeen, Old Aberdeen.
1870. ‡TRAILL, WILLIAM A., M.R.I.A. Geological Survey of Ireland, 14 Hume-street, Dublin.
1875. ‡Trapnell, Caleb. Severnleigh, Stoke Bishop.
1868. ‡TRAQUAIR, RAMSAY H., M.D., F.R.S., Professor of Zoology. Museum of Science and Art, Edinburgh.
1865. ‡*Travers, William, F.R.C.S. 1 Bath-place, Kensington, London, W.*
Tregelles, Nathaniel. Liskeard, Cornwall.
1868. ‡Trehane, John. Exe View Lawn, Exeter.
1869. ‡Trehane, John, jun. Bedford-circus, Exeter.
1870. ‡Trench, Dr. Municipal Offices, Dale-street, Liverpool.
Trench, F. A. Newlands House, Clondalkin, Ireland.
1871. ‡TRIBE, ALFRED, F.C.S. 14 Denbigh-road, Bayswater, London, W.
1879. ‡Trickett, F. W. 12 Old Haymarket, Sheffield.
1877. ‡TRIMEN, HENRY, M.B., F.L.S. British Museum, London, S.W.
1871. ‡TRIMEN, ROWLAND, F.L.S., F.Z.S. Colonial Secretary's Office, Cape Town, Cape of Good Hope.
1860. §TRISTRAM, Rev. HENRY BAKER, M.A., LL.D., F.R.S., F.L.S., Canon of Durham. The College, Durham.
1882. §Trotter, Rev. Coutts, M.A. Trinity College, Cambridge.
1869. ‡Troyte, C. A. W. Huntsham Court, Bampton, Devon.
1869. ‡Tucker, Charles. Marlands, Exeter.
1847. *Tuckett, Francis Fox. 10 Baldwin-street, Bristol.
Tuke, James H. Bank, Hitchen.

Year of Election.

1871. ‡Tuke, J. Batty, M.D. Cupar, Fifeshire.
1867. ‡Tulloch, The Very Rev. Principal, D.D. St. Andrews, Fifeshire.
1881. §Tully, G. T. 10 West Cliff-terrace, Preston.
1854. ‡TURNBULL, JAMES, M.D. 86 Rodney-street, Liverpool.
1855. §Turnbull, John. 37 West George-street, Glasgow.
1856. ‡Turnbull, Rev. J. C. 8 Bays-hill-villas, Cheltenham.
1871. ‡*Turnbull, William, F.R.S.E. 14 Lansdowne-crescent, Edinburgh.*
1873. *Turner, George. Horton Grange, Bradford, Yorkshire.
1882. §Turner, G. S. 8 Carlton-crescent, Southampton.
1875. ‡Turner, Thomas, F.S.S. Ashley House, Kingsdown, Bristol.
1863. *TURNER, WILLIAM, M.B., F.R.S. L. & E., Professor of Anatomy in the University of Edinburgh. 6 Eton-terrace, Edinburgh.
1842. Twamley, Charles, F.G.S. Ryton-on-Dunsmore, Coventry.
1847. ‡TWISS, Sir TRAVERS, Q.C., D.C.L., F.R.S., F.R.G.S. 3 Paper-buildings, Temple, London, E.C.
1882. §Tyer, Edward. Horneck, Fitzjohn's-avenue, Hampstead, London, N.W.
1865. ‡TYLOR, EDWARD BURNETT, D.C.L., F.R.S. Linden Wellington, Somerset.
1858. *TYNDALL, JOHN, D.C.L., LL.D., Ph.D., F.R.S., F.G.S., Professor of Natural Philosophy in the Royal Institution. Royal Institution, Albemarle-street, London, W.
1861. *Tysoe, John. 28 Heald-road, Bowdon, near Manchester.

1876. *UNWIN, W. C., A.I.C.E., Professor of Hydraulic Engineering. Cooper's Hill, Middlesex.
1872. ‡Upward, Alfred. 11 Great Queen-street, Westminster, London, S.W.
1876. ‡Ure, John F. 6 Claremont-terrace, Glasgow.
1859. ‡Urquhart, W. Pollard. Craigston Castle, N.B.; and Castlepollard, Ireland.
1866. ‡Urquhart, William W. Rosebay, Broughty Ferry, by Dundee.
1880. §USSHER, W. A. E., F.G.S. 28 Jermyn-street, London, S.W.

*Vance, Rev. Robert. 24 Blackhall-street, Dublin.
1863. ‡Vandoni, le Commandeur Comte de, Chargé d'Affaires de S. M. Tunisienne, Geneva.
1854. ‡Varley, Cromwell F., F.R.S. Cromwell House, Bexley Heath, Kent.
1868. ‡Varley, Frederick H., F.R.A.S. Mildmay Park Works, Mildmay-avenue, Stoke Newington, London, N.
1865. *VARLEY, S. ALFRED. Hatfield, Herts.
1870. ‡Varley, Mrs. S. A. Hatfield, Herts.
1869. ‡Varwell, P. Alphington-street, Exeter.
1875. ‡Vaughan, Miss. Burlton Hall, Shrewsbury.
1849. *Vaux, Frederick. Central Telegraph Office, Adelaide, South Australia.
1846. ‡Vaux, W. S. W., M.A., F.R.S. 22 Albemarle-street, London, W.
1881. §Veley, V. H., B.A., F.C.S. University College, Oxford.
1873. *VERNEY, Captain EDMUND H., R.N., F.R.G.S. Rhianva, Bangor, North Wales.
Verney, Sir Harry, Bart., M.P. Lower Claydon, Buckinghamshire.
Vernon, George John, Lord. 32 Curzon-street, London, W.; and Sudbury Hall, Derbyshire.
1879. ‡Veth, D. D. Leiden, Holland.
1864. *VICARY, WILLIAM, F.G.S. The Priory, Colleton-crescent, Exeter.
1868. ‡Vincent, Rev. William. Postwick Rectory, near Norwich.
1875. ‡Vines, David, F.R.A.S. Observatory House, Somerset-street, Kingsdown, Bristol.

Year of Election.

1856. ‡VIVIAN, EDWARD, M.A. Woodfield, Torquay.
*VIVIAN, Sir H. HUSSEY, Bart., M.P., F.G.S. Park Wern, Swansea; and 27 Belgrave-square, London, S.W.
1856. §VOELCKER, J. CH. AUGUSTUS, Ph.D., F.R.S., F.C.S., Professor of Chemistry to the Royal Agricultural Society of England. 39 Argyll-road, Kensington, London, W.
‡Vose, Dr. James. Gambier-terrace, Liverpool.

1860. §Waddingham, John. Guiting Grange, Winchcombe, Gloucestershire.
1879. *Wake, Bernard. Abbeyfield, Sheffield.
1870. §WAKE, CHARLES STANILAND. 2 Westbourne-avenue, Hull.
1873. ‡Wales, James. 4 Mount Royd, Manningham, Bradford, Yorkshire.
1869. *Walford, Cornelius. 86 Belsize Park-gardens, London, N.W.
1882. *Walkden, Samuel. Care of Louis de Souza, Esq., 1 Hare-court, Temple, London, E.C.
Walker, Frederick John. The Priory, Bathwick, Bath.
1866. ‡Walker, H. Westwood, Newport, by Dundee.
1855. ‡*Walker, John. 1 Exchange-court, Glasgow.*
1866. *WALKER, JOHN FRANCIS, M.A., F.C.P.S., F.C.S., F.G.S., F.L.S. 16 Gillygate, York.
1881. ‡Walker, John Sydenham. 83 Bootham, York.
1867. *Walker, Peter G. 2 Airlie-place, Dundee.
1866. ‡Walker, S. D. 38 Hampden-street, Nottingham.
Walker, William. 47 Northumberland-street, Edinburgh.
1881. *Walker, William. 14 Bootham-terrace, York.
1863. ‡WALLACE, ALFRED RUSSEL, F.R.G.S., F.L.S. Nutwood Cottage, Frith Hill, Godalming.
1859. ‡WALLACE, WILLIAM, Ph.D., F.C.S. Chemical Laboratory, 138 Bath-street, Glasgow.
1857. ‡Waller, Edward. Lisenderry, Aughnacloy, Ireland.
1862. ‡Wallich, George Charles, M.D., F.R.G.S., F.L.S. 3 Christchurch-road, Roupell Park, London, S.W.
1862. ‡WALPOLE, The Right Hon. SPENCER HORATIO, M.A., D.C.L., F.R.S. Ealing, Middlesex, W.
1863. ‡Walters, Robert. Eldon-square, Newcastle-on-Tyne.
1881. §Walton, Thomas. Oliver's Mount School, Scarborough.
Walton, Thomas Todd. Mortimer House, Clifton, Bristol.
1863. ‡Wanklyn, James Alfred. 7 Westminster-chambers, London, S.W.
1872. ‡Warburton, Benjamin. Leicester.
1874. §Ward, F. D., J.P., M.R.I.A. Clonaver, Strandtown, Co. Down.
1881. §Ward, George, F.C.S. Buckingham-terrace, Headingley, Leeds.
1879. ‡Ward, H. Marshall. Christ's College, Cambridge.
1874. §Ward, John, F.S.A., F.G.S., F.R.G.S. Lenoxvale, Belfast.
1857. ‡Ward, John S. Prospect Hill, Lisburn, Ireland.
1880. *Ward, J. Wesney. 41 Head-street, Colchester.
1863. ‡Ward, Robert. Dean-street, Newcastle-on-Tyne.
1882. §Ward, William. Cleveland Cottage, Hill-lane, Southampton.
*Ward, William Sykes, F.C.S. 12 Bank-street; and Denison Hall, Leeds.
1867. †Warden, Alexander J. Dundee.
1858. ‡Wardle, Thomas. Leek Brook, Leek, Staffordshire.
1865. ‡Waring, Edward John, M.D., F.L.S. 49 Clifton-gardens, Maida Vale, London, W.
1878. §WARINGTON, ROBERT, F.C.S. Harpenden, St. Albans, Herts.
1882. §Warner, F. W., F.L.S. 20 Hyde-street, Winchester.
1872. *Warner, Thomas. 47 Sussex-square, Brighton.

Year of Election.

1856. ‡*Warner, Thomas H. Lee. Tiberton Court, Hereford.*
1875. ‡Warren, Algernon. Naseby House, Pembroke-road, Clifton, Bristol.
1856. ‡Washbourne, Buchanan, M.D. Gloucester.
1876. ‡Waterhouse, A. Willenhall House, Barnet, Herts.
1875. *Waterhouse, Major J. 1 Wood-street, Calcutta. (Care of Messrs. Trübner & Co., Ludgate-hill, London, E.C.)
1854. ‡Waterhouse, Nicholas. 5 Rake-lane, Liverpool.
1870. ‡Waters, A. T. H., M.D. 29 Hope-street, Liverpool.
1875. ‡Waters, Arthur W., F.G.S., F.L.S. Woodbrook, Alderley Edge, near Manchester.
1875. ‡Watherston, Alexander Law, M.A., F.R.A.S. Bowdon, Cheshire.
1881. §Watherston, E. J. 12 Pall Mall East, London, S.W.
1867. ‡Watson, Rev. Archibald, D.D. The Manse, Dundee.
1855. ‡Watson, Ebenezer. 1 Woodside-terrace, Glasgow.
1867. ‡Watson, Frederick Edwin. Thickthorne House, Cringleford, Norwich.
*Watson, Henry Hough, F.C.S. 227 The Folds, Bolton-le-Moors.
1882. §Watson, Rev. H. W., M.A., F.R.S. Berkswell Rectory, Coventry.
1873. *Watson, Sir James. Milton-Lockhart, Carluke, N.B.
1859. ‡Watson, John Forbes, M.A., M.D., F.L.S. India Museum, London, S.W.
1863. ‡Watson, Joseph. Bensham-grove, near Gateshead-on-Tyne.
1863. ‡Watson, R. S. 101 Pilgrim-street, Newcastle-on-Tyne.
1867. ‡Watson, Thomas Donald. 41 Cross-street, Finsbury, London, E.C.
1879. *Watson, William Henry, F.C.S. Braystones, near Whitehaven, Cumberland.
1882. §Watt, Alexander. 89 Hartington-road, Sefton Park, Liverpool.
1869. ‡Watt, Robert B. E., C.E., F.R.G.S. Ashley-avenue, Belfast.
1861. ‡Watts, Sir James. Abney Hall, Cheadle, near Manchester.
1875. *Watts, John, B.A., D.Sc. 57 Baker-street, Portman-square, London, W.
1846. ‡Watts, John King, F.R.G.S. Market-place, St. Ives, Hunts.
1870. §Watts, William, F.G.S. Oldham Corporation Waterworks, Piethorn, near Rochdale.
1873. *Watts, W. Marshall, D.Sc. Giggleswick Grammar School, near Settle.
Waud, Rev. S. W., M.A., F.R.A.S., F.C.P.S. Rettenden, near Wickford, Essex.
1859. ‡Waugh, Edwin. Sager-street, Manchester.
1859. *Waveney, The Right Hon. Lord, F.R.S. 7 Audley-square, London, W.
*Way, J. Thomas, F.C.S. 9 Russell-road, Kensington, London, S.W.
1869. ‡Way, Samuel James. Adelaide, South Australia.
1871. ‡Webb, Richard M. 72 Grand-parade, Brighton.
*Webb, Rev. Thomas William, M.A., F.R.A.S. Hardwick Vicarage, Hay, South Wales.
1866. *Webb, William Frederick, F.G.S., F.R.G.S. Newstead Abbey, near Nottingham.
1859. ‡Webster, John. 42 King-street, Aberdeen.
1834. ‡Webster, Richard, F.R.A.S. 6 Queen Victoria-street, London, E.C.
1882. *Webster, Richard Everard, Q.C. 2 Pump-court, Temple, London, E.C.
1854. ‡Weightman, William Henry. Farn Lea, Seaforth, Liverpool.
1865. ‡Welch, Christopher, M.A. University Club, Pall Mall East, London, S.W.
1881. §Wellcome, Henry S. 111 Marylebone-road, London, N.W.

Year of Election.

1867. §Weldon, Walter, F.R.S. L.&E., F.C.S. Rede Hall, Burstow, near Crawley, Surrey.
1876. §Weldon, W. F. R. St. John's College, Cambridge.
1879. §Wells, Charles A. Etna Iron Works, Lewes.
1881. §Wells, Rev. Edward, B.A. Flamstead Vicarage, Dunstable.
1850. ‡Wemyss, Alexander Watson, M.D. St. Andrews, N.B.
1881. *Wenlock, The Right Hon. Lord. 8 Great Cumberland-place, London, W.; and Escrick Park, Yorkshire.
Wentworth, Frederick W. T. Vernon. Wentworth Castle, near Barnsley, Yorkshire.
1864. *Were, Anthony Berwick. Whitehaven, Cumberland.
1865. ‡Wesley, William Henry. Royal Astronomical Society, Burlington House, London, W.
1853. ‡West, Alfred. Holderness-road, Hull.
1870. ‡West, Captain E. W. Bombay.
1853. ‡West, Leonard. Summergangs Cottage, Hull.
1853. ‡West, Stephen. Hessle Grange, near Hull.
1870. §Westgarth, William. 10 Bolton-gardens, South Kensington, London, W.
1842. Westhead, Edward. Chorlton-on-Medlock, near Manchester.
1882. §Westlake, Ernest, F.G.S. Fordingbridge, Hants.
1882. §Westlake Richard. Portswood, Southampton.
1857. *Westley, William. 24 Regent-street, London, S.W.
1882. §Westlake, W. C. Grosvenor House, Southampton.
1863. ‡Westmacott, Percy. Whickham, Gateshead, Durham.
1875. *Weston, Joseph D. Dorset House, Clifton Down, Bristol.
1864. ‡Westropp, W. H. S., M.R.I.A. Lisdoonvarna, Co. Clare.
1860. ‡Westwood, John O., M.A., F.L.S., Professor of Zoology in the University of Oxford. Oxford.
1882. §Wethered, Edward, F.G.S. 5 Berkeley-place, Cheltenham.
1853. ‡Wheatley, E. B. Cote Wall, Mirfield, Yorkshire.
1866. †Wheatstone, Charles C. 19 Park-crescent, Regent's Park, London, N.W.
1847. ‡Wheeler, Edmund, F.R.A.S. 48 Tollington-road, Holloway, London, N.
1878. *Wheeler, W. H., C.E. Churchyard, Boston, Lincolnshire.
1879. *Whidborne, Rev. George Ferris, M.A., F.G.S. Charante, Torquay.
1873. ‡Whipple, George Matthew, B.Sc., F.R.A.S. Kew Observatory, Richmond, Surrey.
1874. ‡Whitaker, Henry, M.D. 33 High-street, Belfast.
1859. *Whitaker, William, B.A., F.G.S. Geological Survey Office, 28 Jermyn-street, London, S.W.
1876. ‡White, Angus. Easdale, Argyleshire.
1864. ‡*White, Edmund. Victoria Villa, Batheaston, Bath.*
1882. §White, Rev. George Cecil, M.A. St. Paul's Vicarage, Southampton.
1876. *White, James. Overtoun, Dumbarton.
1873. ‡White, John. Medina Docks, Cowes, Isle of Wight.
1859. ‡White, John Forbes. 16 Bon Accord-square, Aberdeen.
1865. ‡White, Joseph. Regent's-street, Nottingham.
1869. ‡White, Laban. Blandford, Dorset.
1859. ‡White, Thomas Henry. Tandragee, Ireland.
1877. *White, William. 365 Euston-road, London, N.W.
1861. ‡Whitehead, James, M.D. 87 Mosley-street, Manchester.
1861. *Whitehead, John B. Ashday Lea, Rawtenstall, Manchester.
1861. *Whitehead, Peter Ormerod, C.E. Drood House, Old Trafford, Manchester.

Year of Election.

1855. *Whitehouse, Wildeman W. O. Science Club, Savile-row, London, W.

1871. ‡Whitelaw, Alexander. 1 Oakley-terrace, Glasgow.

1881. §Whitfield, John, F.C.S. 113 Westborough, Scarborough.

1866. ‡Whitfield, Samuel. Eversfield, Eastnor-grove, Leamington.

1874. ‡*Whitford, William. 5 Claremont-street, Belfast.*

1852. ‡Whitla, Valentine. Beneden, Belfast.

Whitley, Rev. Charles Thomas, M.A., F.R.A.S. Bedlington, Morpeth.

1870. §Whittem, James Sibley. Walgrave, near Coventry.

1857. *Whitty, Rev. John Irwine, M.A., D.C.L., LL.D. 4 Roderick-road, London, N.W.

1874. *Whitwell, Mark. Redland House, Bristol.

*Whitworth, Sir Joseph, Bart., LL.D., D.C.L., F.R.S. Stancliffe, Matlock, Derbyshire.

1870. ‡Whitworth, Rev. W. Allen, M.A. Glenthorne-road, Hammersmith, London, W.

1865. ‡Wiggin, Henry. Metchley Grange, Harborne, Birmingham.

1881. §Wigglesworth, James. Wakefield.

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